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SCIENTIFIC LEADER OF THE EXPEDITION

VOLUME IV

Bottom Investigations

FASC. I

GÖTEBORG
ELANDERS BOKTRYCKERI AKTIEBOLAG

REPORTS OF THE SWEDISH DEEP-SEA EXPEDITION. VOL. IV
BOTTOM INVESTIGATIONS. NO. 1

SOUND EXPLORATIONS

BY

WALODDI WEIBULL

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Introduction

In 1943, through the courtesy of Professor HANS PETTERSSON, the AB. BOFORS was afforded the opportunity of using the excellent topographic and laboratory conditions at Bornö Station on the Gullmar Fjord, for studying the physical aspects of underwater explosions. In the first place, the experiments, made by means of an instrumentation specially developed for the purpose, aimed at a comparison between various kinds of high explosives for military uses. Professor PETTERSSON, however, proposed another application of the methods, with a purely scientific aim, viz. to measure the thickness of submarine sediment layers by recording the acoustic waves reflected against sub-bottom strata within the sediment. The idea seemed attractive, since the same apparatus might, with some modifications, be employed for that purpose even though — as was later proved by experience — rather considerable difficulties might be encountered in practice, especially when the explorations had to be transferred to the deep sea.

Preliminary experiments were immediately started at the Bornö Station. Since promising results had been obtained, it was obvious that continued investigations had to be transferred to greater depths than those found in the Gullmar Fjord. The Swedish research ship the SKAGERAK was then kindly made available by the Swedish Hydrographic-Biologic Commission during several expeditions which, because of the World War, in the beginning had to be restricted to Swedish Coastal Waters.

The first of these expeditions was carried out on the 7th—9th August, 1944, with the purpose of studying hydrophones of various designs. This expedition as well as two following expeditions, on the 11th—13th October and the 5th—7th April, also with the SKAGERAK were extended to the West Coast of Sweden only. The maximum water depth attainable during these three expeditions was 250 m.

After the World War had ended, new possibilities were opened, and on the 7th August, 1945, the SKAGERAK started on a four-day cruise to the water south of Norway, were the maximum depth (680 m) within Scandinavian waters is located. Profiting by these new possibilities, hydrophones were tested, and the shooting procedure examined.

The experiences gained during these expeditions were valuable, and could be used for improvements of the instrumentation and for the definite designing of a hydrophone buoy intended for a planned expedition to the Mediterranean. After having been finished this hydrophone buoy, which is described in a following chapter, was, to begin with, trimmed during an expedition on the 10th—12th October, 1945, in the Gullmar Fjord and had then to go through the final test during the expedition with the SKAGERAK to the Mediterranean on the 15th April to the 12th May, 1946.

This expedition was, in turn, a preliminary to the planned Swedish Deep-Sea Expedition with the ALBATROSS. The most important observation made during the SKAGERAK expedition was that the amplifier had to be made very insensitive to the electric and acoustic disturbances that are in so ample a measure met with on board a ship. Founded on this experience, a new amplifier was designed and built in the Physical Research Department of AB. BOFORS. A great deal of care was bestowed on the mechanical and acoustical insulation of the different details, through spring suspension. The design of the amplifier as a whole, was also given due consideration, with regard to the special difficulties encountered in a tropical climate.

The practical tests of this amplifier were carried through, thanks to the courtesy of Vice Admiral H. STRÖMBÄCK, Commander-in-Chief of the Royal Swedish Navy, during two expeditions with the patrol vessel VÄKTAREN, and two expeditions with the submarines NAJADEN and SVÄRDFISKEN, all of them in the Baltic, where a maximum depth of 430 m is to be found outside Nynäshamn. Through these expeditions an opportunity of making very careful and complete trials was given. As a proof of the good results may be taken the fact that the final amplifier behaved perfectly during the 15 months on board the ALBATROSS, under severe climatic conditions, often with high temperatures, great humidity, and in a heavy sea.

During the first expedition with the VÄKTAREN, on the 1st—5th July, 1946, some preliminary experiments with a radio buoy were started, for the purpose of taking up a refraction method on the programme. As it was soon found that the seismic explorations on board the ALBATROSS had to be limited to the reflection method only, these experiments were never finished.

The second expedition with the VÄKTAREN on the 4th—6th July, 1946, and the expeditions with the SKAGERAK on the 28th—31st October, 1946, and with the NAJADEN on the 1st—3rd June, 1947, were principally devoted to experiments with the electrolytic hydro-

TABLE 1. Expedition list.

Year	Date	Ship	Max. depth m	Hydrophone
1944	7—9 Aug.	Skagerak	250	Electrodynamic, ASEA Quartz crystal, Bofors
1944	11—13 Oct.	Skagerak	110	Quartz crystal, Bofors
1945	5—7 April	Skagerak	190	Quartz and Seignette crystals, Bofors
1945	7—10 Aug.	Skagerak	680	Same as preceding
1945	10—12 Oct.	Skagerak	120	Quartz crystal mounted in a buoy, Bofors
1946	15 April—12 May	Skagerak	2800	Same as preceding
1946	1—5 July	Väktaren	430	Same as preceding
1946	4—6 Sept.	Väktaren	430	Electrolytic, Bofors
1946	28—31 Oct.	Skagerak	680	Electrolytic, sea water Quartz crystal in bonoplex sheath, Bofors
1947	1—3 June	Najaden	430	Same as preceding
1947	4 July—20 Nov.	Albatross	5060	Electrodynamic, Albatross
1947	27—28 Oct.	Svärdfisken	430	Electrodynamic, Bofors
1947, 1948	17 Dec.—4 Oct.	Albatross	8800	Same as preceding

phones. The expedition with the SVÄRDFISKEN on the 27th—28th October, 1947, had the purpose of testing a modified electrodynamic hydrophone, the design of which was based on experiences gained during the early part of the ALBATROSS expedition just then going on. After the expedition, two such hydrophones were sent by air to Honolulu. After their arrival, they were used exclusively, with entire satisfaction, during the rest of the ALBATROSS expedition.

A survey of the different expeditions and the hydrophones used is given in TABLE 1.

Methods

The principal aim of the seismic measurements during the expedition was to determine the thickness of the ocean sediments.

There are two different methods of exploring the bottom by means of sound waves, viz.: the refraction and the reflection methods.

The *refraction method* is characterized by the use of a sound pulse usually generated by an exploding charge of high explosive, which passes through the water, thereafter following horizontal surfaces of discontinuity in the sediment, and being recorded by at least two, but preferably several hydrophones, placed at different distances from the source. By comparing the arrivals of the signals which have travelled different paths, it is possible to calculate the depths of the horizons. An important advantage of this method lies in the possibility of determining, at the same time, also the sound velocity in the individual layers, which may facilitate their identification. On the other hand, the shooting procedure is rather complicated and timeabsorbing, a fact that prevented the carrying out of the original plans to apply this method during the ALBATROSS expedition.

The *reflection method* does not allow of determinations of the sound velocity in the sediment, which is a deplorable drawback. But it has the great advantage that the charge and the hydrophones may be manipulated from the same place. Each record can therefore be made in a few minutes, without disturbing other work on board the ship. The general arrangement is shown in Fig. 1. The hydrophone is lowered from the ship to a depth which, after

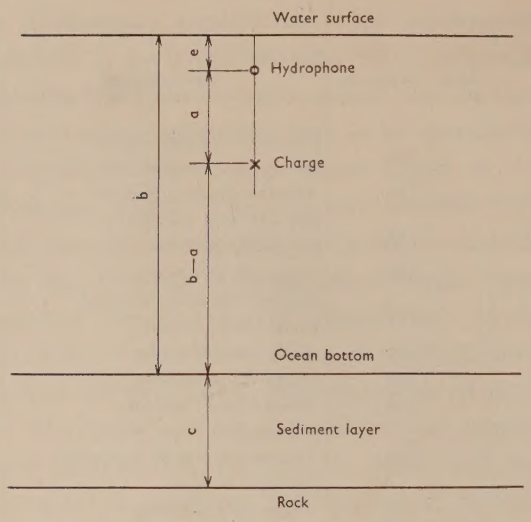

Fig. 1.

some experimenting was found to be most favourable at 20 m below the water surface. A depth-charge is fired by a hydrostatic fuse when it reaches a pre-determined depth, varied at will between 500 and 6500 m. At the explosion, a sharp sound pulse is emitted, which reaches the hydrophone both directly and after some reflections at different levels. If there exists a sediment layer of definite thickness, as shown in the figure, a part of the sound pulse will be reflected at its upper surface i. e. the ocean bottom. Another part will pass through the sediment layers, and will be reflected against rocks or other horizons, and will thus arrive to the hydrophone with a time lag that depends on the thickness of the sediment, and its sound velocity. The arrivals of the different reflections are recorded by an oscilloscope or by a wire recorder, and the time lags are measured in this way. If the hydrophone and the amplifier together have a sufficient sensitivity, repeated reflections from the bottom, the sub-bottom strata, if any, and the water surface will be recorded. As demonstrated in the following, this fact constitutes an indispensable method for the interpretation of the records.

It may be of importance to point out that these reflections are generated in surfaces with discontinuity in the acoustic impedance only, while the refraction method makes use of discontinuities in the sound velocity. For this reason, it may be possible that a horizon detected by one of the methods may be overlooked when the other method is used, as is demonstrated through some investigations by Hill & Swallow (1950).

Instrumentation

Charges

It is very desirable that the source of seismic energy should generate a sharp and concise acoustic pulse. For this reason, charges of high explosives are mostly used.

During some investigations of underwater explosions, it was observed by Weibull (1925) that the exploding charge emitted a series of distinct pulses, at time intervals which were proportional to the cubic root of the weight of the charge. It seemed plausible to assume that these pulses were originated by oscillations in the spherical volume of gas into which the explosive had been converted. If so, the time interval ought to decrease with an increasing depth of the charge. A complete verification of this hypothesis was obtained by the author during research work under contract with the Royal Swedish Navy, in 1928, by varying the depth from 10 to 70 m. These investigations were completed in 1945 by extending the range of the depth to the limits of 4 and 280 m, and of the weights to 48 grammes and 2.3 tons. A survey of these investigations is made by Rabe (1945).

The results for TNT may be sumarized in the formula:

$$t = 2.1\, W\, (h + 10.3)^{-0.83} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where t = time interval between the first and the second bubble pulse in secs., W = weight in kg., and h = depth of charge in m.

TABLE 2. Time interval between 1st and 2nd bubble pulse in ms at various depths and charges.

Charge		Depth h in metres						
Notation	gram	0	5	40	500	2500	4500	6500
Det.	< 1	30.3	21.8	8.1	1.2	0.3	0.2	0.1
Hydrost.	4	48.2	34.7	12.9	1.9	0.5	0.3	0.2
1	174	169.4	122.0	45.4	6.6	1.7	1.1	0.8
2	344	212.4	153.0	57.0	8.3	2.2	1.4	1.0
3	514	243.0	175.0	65.2	9.5	2.5	1.6	1.2
4	684	267.3	192.0	71.7	10.5	2.8	1.7	1.3
9	1534	349.7	251.8	93.8	13.7	3.6	2.2	1.7

Time interval $t = 2.1\ W^{1/3}\ (h + 10.3)^{-0.83}$ sec. W in kg., h in m., explosive TNT

Notations: Det. = detonator No. 8
Hydrost. = hydrost. fuse only
1 = hydrost. fuse + 1 charge
2 = hydrost. fuse + 2 charges
etc.

The bubble-pulse intervals for charges and depths used during the ALBATROSS expedition were computed and may be found in TABLE 2.

A very satisfactory checking of equ. (1) is obtained through a publication by EWING, WOOLLARD, VINE, and WORZEL (1946) who have independently and by quite different means found an identical formula with values of the coefficients differing less than 1 % from the above-mentioned one. This problem has also been treated by ARONS, SLIFKO, and CARTER (1948).

As shown in TABLE 2, the time intervals will be inconveniently large at small depths. This has also been observed by LAY (1945) who prevented the oscillations by bringing the charge close enough to the surface of the water, so that the gas bubble would burst through the surface on first expansion. The same method was used by HERSEY & EWING (1949) who started their explorations with a charge depth of some hundred feet but later on changed it to two or three feet below the surface.

This method may be the only practicable one for shallow water, but at greater depths, it is much better to locate the charge as deep as possible. In this way, the pulse frequency will be sufficiently high so as not to complicate the records, the explosive will be more efficiently used, and the reflections from the bottom topography will be less disturbing. The greater part of the charge depths chosen during the ALBATROSS expedition were also between 500 and 6.500 m.

During the preliminary expeditions, and in a few special cases during the ALBATROSS expedition, the charge was initiated through a firing cable. The initiation was thus completely under control, and the moment of explosion could be marked (symbol 0) on the record, as shown in the records Nos. 30 S and 55 S. These records were taken in 1946 during the preliminary expedition with the SKAGERAK, in the Mediterranean.

The handling of the cable, however, was too troublesome at charge depths greater than 300 m, and the method of initiation had to be changed. This was done by introducing *a*

Fig. 2.

hydrostatic fuse which was designed and manufactured by the AB Bofors. The charge is initiated mechanically by a membrane which bursts under the influence of the water pressure when a predetermined depth is reached. The main part of the *depth- charge* consists of a steel tube with a lead-filled point. The inner diameter is 40 mm and the outer diameter 47 mm. The length is either 500 or 1000 mm. (A 1000 mm depth-charge is seen in Fig. 2.) Just before dropping the bomb, the hydrostatic fuse and up to 4 charges in the first case and up to 9 charges in the latter case are introduced into the tube and sealed. Each of these TNT charges has a diameter of 39 mm, a length of 100 mm and a weight of 170 grammes. The fuse is charged with 4 g of TNT. The different charges obtainable in this way are given in TABLE 2.

The dimensions of the membranes were designed to give rupture at a depth of 500, 1000, 2500, 4500 or 6500 m. The actual depths show a small scatter around a mean, which deviates, to some extent, from the nominal values, as seen in TABLE 3, where *a* denotes the actual depth in m, *t* the sinking time, and thus a/t the average sinking speed in m/s. The symbols 4/1000, 4/2500, and 4/4500 indicate a 500-mm tube, with 4 charges and the fuse provided with membranes for 1000, 2500, and 4500 nominal depths, respectively. The symbols 9/1000, 9/2500, and 9/4500 denote a 1000-mm tube with 9 charges etc. The actual depths have turned out to be a little smaller than the corresponding nominal depths of 1000 and 4500, and a little larger than the corresponding nominal depth of 2500. The sinking speed is practically independent of the depth. The slightly smaller values of the 1000 m. bombs are very likely due to the comparatively greater influence of the acceleration period at shorter sinking times.

The behaviour of the longer bomb is very peculiar. One half of them had a sinking speed of about 7.5 m/s and the other half had a speed

TABLE 3. List of actual charge depths in m., and sinking times in sec. for nominal depths 1000, 2500, and 4500 m.

4/1000			4/2500			4/4500		
a m	t s	a/t m/s	a m	t s	a/t m/s	a m	t s	a/t m/s
752	135	5.57	2568	560	4.59	4139	704	5.88
781	135	5.78	2625	432	6.08	4295	73	5.82
747	132	5.66	2568	442	5.81	4060	675	6.01
768	140	5.48	2570	4977	5.17	4165	706	5.90
768	139	5.52	2573	415	6.20			
						9/1000		
734	138	5.38	2630	434	6.06			
779	127	6.13	2627	435	6.04	793	101	7.85
774	128	6.05	2855	436	6.55	703	(330	2.13)
798	145	5.50	2602	415	6.27	—	(387)	—
768	132	5.82	2706	4330	6.29	737	102	7.22
645	120	5.38	2557	428	5.97	744	102	7.54
745	124	6.00	2574	505	5.10			
736	130	5.66	2590	425	6.09	9/2500		
789	131	6.02	2519	431	5.84			
749	127	5.90	2663	436	6.11	2773	355	7.81
653	123	5.30				2618	(1143	2.29)
						2520	352	7.16
749	132	5.69	2615	4488	5.88	2612	(1162	2.25)
						2630	354	7.48

a = actual depth
t = sinking time
a/t = sinking speed

of a little more than 2 m/s only. The lower values are certainly caused by an instability in the movement of the long tubes. The actual depth seems to be quite independent of the tube length. The mean values of the sinking times of the shorter bombs are: 2 min. 15 sec., 7 min. 30 secs. and 11 min. 45 secs, corresponding to 1000, 2500, and 4500 m depths.

Already at the beginning of the expedition, it was observed that the ocean bottom has a topographic relief, spread over much wider regions than suspected, which highly disturbed the recording. It was then urged by Professor PETTERSSON that the charge should be located in the uppermost layers of the sediment, as side reflections from the bottom topography would then become eliminated or, at least, considerably weakened. This assumption proved to be quite correct, as will be shown

later on by examples. Having very little time for experimenting, it was deemed necessary to devise a contrivance that would fit in with the existing instrumentation. For this reason a *retardation device* to be adapted to the depth charge was designed, manufactured and sent by air from Bofors to the ALBATROSS, at this time arriving at Honolulu. The principle of this retardation device was based upon the idea that water had to flow through a plug of sintered copper powder. The pressure necessary to burst the membrane of the hydrostatic fuse, was thus delayed so much that the depth charge reached the bottom before the explosion occurred. Some bottom explosions have been recorded, but some of the charges exploded before reaching the bottom, as the sinking speed of the depth charges had, in some cases, been decreased by the altered design.

After having left the ALBATROSS in Panama, the author visited the Woods Hole Oceanographic Institution, on his way home. He had the benefit of having demonstrated to him the implosion bomb invented and used in the SOFAR system, and described by STIFLER & SAARS (1948). The principle is very simple and attractive, and no explosive is used. The energy is obtained by the collapsing of an air-filled steel tube under the influence of the surrounding water pressure. After the author's return to Sweden, a few implosion bombs were manufactured and successfully tested when the author had rejoined the expedition in the Mediterranean, in June of the following year. The signals generated in this way are very short and concise, as shown in Nos. 326 a and b where the bomb collapsed at 1760 m. The advantage of not having any explosive is counter-balanced by the fact that the implosion bomb is much more bulky than a charge with the same energy content, but at great depths the use of these bombs may sometimes be quite advantageous.

Hydrophones

In the preliminary experiments at Bornö Station, and during the expeditions in the Baltic, off the West Coast of Sweden and in the Mediterranean, a great many designs, based on piezoelectric, electrolytic and electrodynamic principles, have been completed.

Apart from a short trial with an electrodynamical hydrophone which was too undamped, the first measurements were made with a *piezoelectric quartz-crystal hydrophone.* The crystals were enclosed in a »bonoplex» sheath, and the hydrophone was suspended from the ship at a depth of about 1 meter below the surface. The amplifier was placed on board the ship, but in spite of attempts to suspend the valves by spring coils, no satisfactory results were obtained, because of vibrations on board. Some disturbances were also generated by the pressure-sensitive cable in the water. For this reason, the amplifier was moved from the ship and suspended by spring coils in a surface buoy. The individual valves entering into the amplifier were also suspended in the same manner. The electric cable from the amplifier passed through two steel tubes (shown in Fig. 3) down to the two crystals, 50 mm in diameter, which were mounted between three steel discs and carefully insulated. The crystals, which behaved very well indeed during the preliminary expedition in the Mediterranean, had been obtained through the courtesy of the Salford Electrical Instruments Ltd., England. With the buoy floating on the surface, the crystals were at a depth of 1.4 meters below the surface. A record made with the aid of this hydrophone buoy and a Siemens oscillograph is shown in No. 305. The charge was then 5 kg of TNT, at a depth of 300 m.

In general, this arrangement worked quite satisfactorily. Even with a high degree of amplification one was relatively independent of disturbances within the hull of the ship.

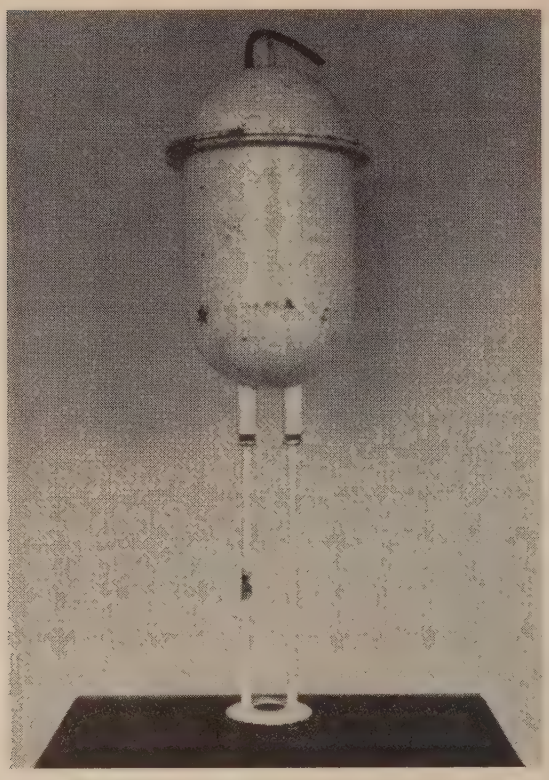

Fig. 3.

With a strong wind blowing, there appeared some disturbances from the waves striking against the ship and the buoy. On the other hand, even a strong swell produced no disturbances at all.

Nevertheless, it was deemed too risky to depend entirely on a crystal hydrophone during the long expedition with the ALBATROSS, as it requires very perfect insulation. For this reason, other principles were studied.

An *electrolytic hydrophone*, shown in Fig. 4, consisted of two concentric electrodes and two plexiglass membranes, which all together constituted a container for the electrolyte, copper disulphate. The electric resistance was influened by the shock waves. It was found that the design could be much simplified by using ordinary sea-water as the electrolyte in which case the membranes could be removed and the hydrophone thus only consisted of the two concentric electrodes, which conducted an electric current of 0.2—0.8 amp. A still greater simplification was obtained by using an uninsulated copper sphere, 18 mm in diameter, suspended in the water, and carrying an electric current of 0.2 amp. This simple arrangement worked quite satisfactorily.

At the start of the ALBATROSS expedition, the stock of hydrophones consisted of five electrolytic hydrophones, one of them of the sea-water type, and two quartz-crystal hydrophones. They were used in the beginning. After having left Portugal, an electrodynamic hydrophone was improvised by taking an ordinary telephone receiver from the radio station on board and enclosing it in the case of a small photometer (used for measurements of submarine daylight, as described by JERLOV, Volume III, Fasc. I, p. 9, Fig. 1). The window and the opal glass were replaced by a 2-mm steel membrane against which the membrane of the radio receiver was pressed by a spring. The two membranes were separated by a thin packing, producing an air interspace between them of a few tenths of a millimeter. This temporary arrangement turned out to be much superior in sensitiveness and freedom from disturbances by wind and waves to the electrolytic and piezoelectric hydrophones. The electric resistance of the receiver was 2000 ohms. In Funchal, Madeira, two radio receivers with a resistance of 1300 ohms were procured, and mounted in two cases, one with a 2-mm and the other with a 3-mm membrane. These

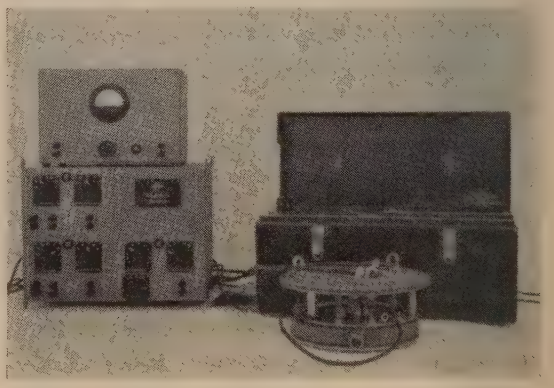

Fig. 4.

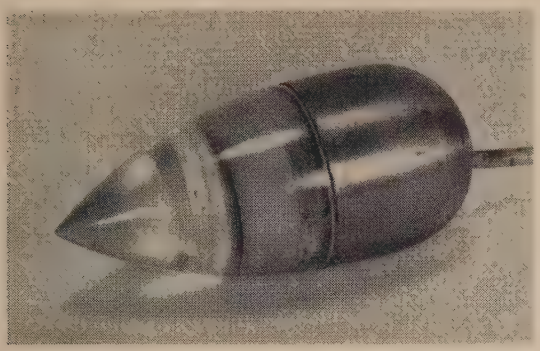

Fig. 5.

two hydrophones worked very well, and all the shots from No. 29 to No. 183 were recorded by means of these hydrophones. Record No. 29 shows an exemple of their sensitivity. The charge was less than one gramme (a detonator), at a depth of 40 m, the water depth 5,400 m, and the amplification 1: 20. Nevertheless, the signals *P3* and *P4*, corresponding to a travel distance of 21,600 m, were quite recognizable. Another record, No. 74, illustrates the independance of wind and waves, having been taken in a wind of 18 m/s and a swell of No. 6 in the Douglas sea-scale.

The records Nos. 184—432 were taken with a slightly modified construction, the design of which is shown in Fig. 5. The main difference from the preceding type lies in the streamlined endpiece, made of plexiglass, which was introduced to prevent the wobbling of the hydrophone when the ship drifted with stopped propellers. (The material, plexiglass, was chosen because of its acoustic impedance being much the same as water.) This source of acoustic disturbances had been observed on earlier occasions. The telephone receiver was procured from AB L. M. Ericsson, Stockholm, and had a resistance of 1000 ohms. Two hydrophones of this type were made in Bofors and sent by air to Honolulu.

Amplifiers

During the earlier part of the expedition, the shots were recorded by an oscilloscope. In this case an amplifier was used, the block diagram of which is shown in Fig. 6. Two such amplifiers and one RC generator, with a frequency of 15 c/s (One period = a travel time of 100 m in water) for time indication, were mounted in a common case, shown in Fig. 4. An identical aggregate kept in reserve, never had to be used. One detail of interest may be mentioned. In order to withstand the heat and humidity in the tropical regions, all interior parts of the aggregates were sprinkled with liquid plastic, which after having dried gave a good and reliable protection.

The amplification was changeable by the following steps: 1/1, 1/2, 1/5, 1/10, 1/20, 1/50, and 1/100. The lower cut-off (not very sharp), could be varied between 85 and 450 p/s. The higher values did indeed eliminate some of

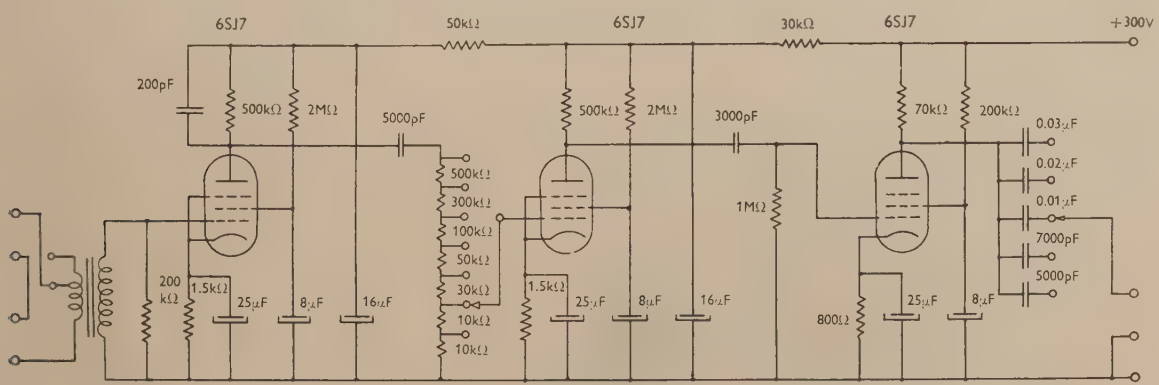

Fig. 6.

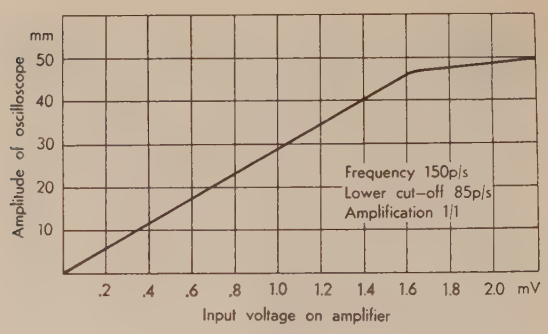

Fig. 7.

the disturbances from the net, but might be dangerous, as they may weaken some of the signals from the sub-bottom strata. The sensitivity of the amplifier is constant up to an input voltage of 1.6 *mV* after which it is intentionally decreased, as shown in Fig. 7.

Most of the shots from No. 198 were recorded by a wire recorder. In this case, the amplifier had to be changed. Its block diagram is shown in Fig. 8.

Oscilloscope

The oscilloscope was of Siemens' manufacture, with three galvanometers, two of them connected to one hydrophone each, and one connected to the RC generator for time indication. The coil of the galvanometers had an natural frequency of 2000 c/s and a sensitivity of 14 mm/mA. The speed of the recording paper was almost in all records about 4 cm/s. The oscilloscope is shown in Fig. 4.

Wire Recorder

The original shooting procedure was based on the concept of locating the charge as deep as possible, but leaving at least 500 m of water to the bottom. The oscilloscope was started when the shot was heard, giving sufficient time to obtain full speed of the recording paper before the first bottom reflection arrived to the hydrophone.

Already during the first stage of the expedition, it was found, as already mentioned, that the bottom of the ocean was much more rugged than expected, and that it was desirable to locate the charge on the bottom, but in doing so, however, no forewarning would be obtained, and the oscilloscope must therefore be started an inconveniently long time before the shot.

It then occurred to the author that a way out of this difficulty would be to introduce a magnetic recorder. Such an apparatus was therefore built on board the ALBATROSS in a very clever and successful way by the author's assistant, VIGGO WENTZEL, using spare parts bought in Honolulu.

There are many advantages obtained by using magnetic recording, in addition to the fact that the recorder can be started a very

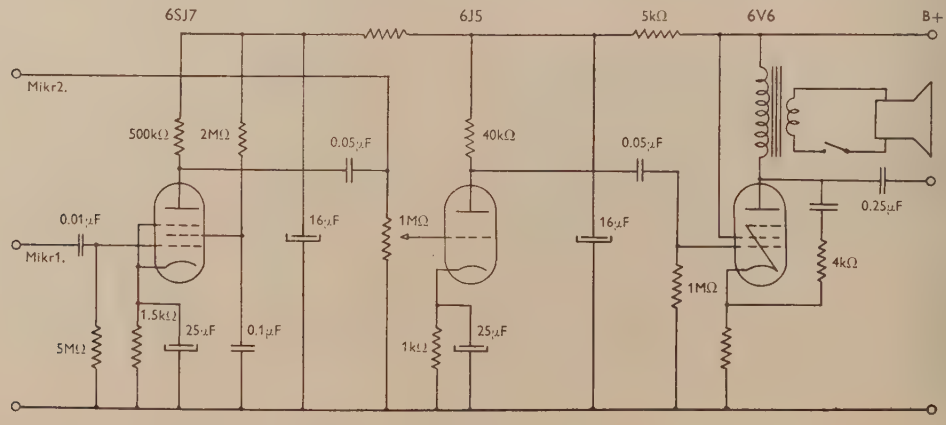

Fig. 8.

long time, one hour or less, before the shot is fired. The records are easy to store, and it is easy to reproduce the recording with appropriate amplification and speed of the recording paper. It is also possible to introduce electric filters, and to analyze the frequencies of the different signals in the same record. The first shot, recorded in this way, was fired on the 26th December, 1947. Reproductions of the recordings, four years later, have shown no apparent deviation from the originals.

The parts of the recorder were from Wirecorder, Detroit. The wire had a diameter of 0.1 mm and a recording speed of 2 ft/sec. The bias frequency was 35 kc/s and the maximum recording time one hour.

Shooting Procedure

In spite of the great sensitivity of the hydrophones, core sampling and other work on board could be carried on during the shooting. The only intolerable source of acoustic disturbances were the propellers, which had to be stopped during recording. In a strong wind, the heavy rigging of the ship caused a considerable drift, and the hydrophones were forced to the surface. For this reason the propellers had to be stopped at the latest moment possible.

When only one depth charge had to be dropped, the procedure was quite simple. The interpretation of the record, however, requires two or three shots at the same station, and from a drifting ship, with the smallest possible time lag.

After more experience had been acquired, it was possible to drop and to record three charges at the depths 500, 2,500, and 4,500 in less than 15 minutes, according to the following time table:

The hydrophones were lowered to 20-m depth while the ship was making about one knot against the wind, the cables then showing 30° astern.

drop the 4,500 m charge ..	0	min.	00 secs.
» » 2,500 » » ..	2	»	00 »
» » 500 » » ..	6	»	30 »
stop the propellers	7	»	00 »
explosion of the 500 m. charge	7	»	30 »
explosion of the 2,500 m charge	9	»	30 »
explosion of the 4,500 m charge	11	»	45 »

The last signal having been recorded, which will take place not later than after 14 min. the hydrophones were taken on board, and the propellers could be started.

At depths of between 3,000 and 5,000 m, two depth charges would be dropped according to the following time table:

drop the 2,500 charge	0	min	00 secs.
» » 500 »	4	»	30 »
stop the propellers	5	»	00 »
explosion of the 500 charge	5	»	30 »
» » » 2,500 »	7	»	30 »

Interpretation of the Records

The reflections of the shock wave from the bottom, with its varying topographic relief, from strata beneath the bottom, from the water surface, and from objects in the water, as well as noises and disturbances, give the records an appearance which sometimes may be very difficult to interpret.

The integrating parts of the record, the signals, can be identified by two different methods. The first way is to make a study of the positions of the signals and their dependence on the depth of the charge and the water depth (position analysis). The second method is to analyze the spectral composition of the signal (frequency analysis).

The appearance and relative amplitude of the signals may also render valuable information. The knowledge about the bottom topography sometimes gives support in the inter-

pretation of the oscillograms, particularly when it comes to a decision between reflections from the topographic relief of the bottom and from sub-bottom strata.

Classification, Symbols, and Nomenclature of the Signals

Leaving out electric and acoustic disturbances, the signals may be divided into two classes: direct and reflected signals. The first class contains the *PO* signal, generated by the direct shock wave from the source of seismic energy, usually a detonating charge of high explosive, and the *A* signals, generated by noises from bathy-pelagic animals. The second class includes five different types of signals, emanating from reflections at different surfaces. They will be denoted by the letters *P*, *B*, *D*, *G*, and *S*.

Each of these types appear generally as a series of consecutive signals, denoted by the figures 1, 2, 3 etc. according to their chronological order.

Finally, if the hydrophone is not located too close to the surface in relation to the resolving power of the recording instrument, each signal may be split up into two parts, one generated by the wave going upwards, the other generated when the wave passes the receiver on its way downwards after reflection at the water surface. These two parts will be denoted by the letters *a* and *b*.

Thus the symbol *P2a*, denotes a signal of *P* type which, after two reflections, has reached the hydrophone on its way upwards. The symbol *Ab*, denotes a signal emanating from some animal in the water and passing the hydrophone after having been reflected at the water surface in a downward direction.

The signals may also be classified into primary and secondary signals.

The P signals, or primary signals, appear under all circumstances, even if there are no sediment layers or reflecting surfaces other than an even bottom and the water surface. The signal *PO* has already been mentioned as a direct signal. All the others are reflected signals. *P1* is generated by the shock wave after one reflection at the bottom, *P2* after two reflections, one at the surface, one at the bottom, *P3* after three reflections, one at the bottom, one at the surface, one at the bottom, etc.

The primary signals form the frame work of the diagram of signals. In the interpretation of the records it is therefore advisable to start by identifying these signals, which generally does not cause any difficulties, their positions being unambigously determined — as will be shown in the following chapter — by the depths of the bottom, the charge, and the hydrophone.

All the other signals, i. e. the *A*, *B*, *D*, *G*, and *S*, are secondary signals.

The A signals, or Animal signals, emanate from fishes, shrimps or other animals living in the water at different depths.

The B signals, or Bottom signals, are due to spurious reflections from the topographic relief of the bottom, either from undulations or from single objects, isolated blocks, rocks etc.

The D signals, or the Deep-scattering-layer signals, are reflected from different depths above the bottom. (In the beginning, these layers were assumed to have come from something inanimate but are now without a doubt identified as living creatures. The reflecting layers are presumably composed of fish, the air bladders of which are apt to return a strong echo).

The G signals, or Gas-bubble signals, are reflected at the gas bubble of the explosion when the shock wave strikes the bubble after having been reflected at least one time at the water surface.

The S signals, or Sub-bottom signals, are reflected from horizons beneath the bottom.

The Diagram of Signals

With the exception of the *A* signals, which may appear anywhere in the diagram, all signals have their positions determined by the depths of the source of pulse energy, of the hydrophone and of the different reflecting surfaces, such as the bottom, the sub-bottom strata and scattering layers in the water.

At the explosion, a shock wave is sent out in all directions, with a velocity higher than normal during the first moments. If the charge is small, this increase disappears after a few metres only, and thus no correction is needed. Tables of the normal velocity of sound in pure water and sea water in 52 areas of the ocean have been calculated, prepared, and edited by MATTHEWS (1939).

If the speed of sound in the recording film is constant, each distance covered by the shock wave will be proportional to the corresponding distances on the record, the proportion being the same as that between the velocity of sound and that of the recording medium (film, tape or wire).

The positions of the P signals in the records are determined uniquely by the depths of the charge *a*, of the hydrophone *e*, and of the bottom *b*. The direct shock wave, when passing the hydrophone, generates the signal *POa* after having travelled a distance of *a—e*. On its way downwards after reflection at the surface, it passes the hydrophone anew, generating the signal *POb* after having travelled a distance of *a+e*. In this way there will appear a series of consecutive signals *P2a* and *b*, *P4a* and *b* . . . . ., *P2na* and *b* with travelling distances of $a + 2nb \mp e$, where $n = 0, 1, 2,$ etc.

At the moment of explosion, a shock wave is also sent downwards. After a reflection at the bottom, it passes the hydrophone with a covered distance of 2b—a—e, generating the signal *P1a* which is the first member of a series of consecutive signals *P1a* and *b*, *P3a* and *b* . . . . , *P (2n+1)a* and *b*, with covered distances of $2(n + 1) b - a \mp e$, where $n = 0, 1, 2,$ etc. The diagram of these primary signals is shown in Fig. 9.

The position of a B signal in relation to a corresponding P signal in the record depends on the depths of the hydrophone *e*, the charge *a*, and the position of the reflection point B at the bottom, assumed to lie at a distance of *b* beneath the surface, and at a distance, *f*, from the perpendicular through the hydrophone and the charge, as shown in Fig. 10, where the charge has been given three alternative positions, A0, A1, and A2.

The following table (p. 19) gives the time lag between the *B* and the *P* signals.

From this table it will be seen that only if the charge is located at the surface, the time lag between *B*1 and *P*1 is equal to that between *B2* and *P2*. In all other cases the time lag between *B1* and *P1* is greater than that between *B2* and *P2*, and increases with the charge depth. This is an important property of the B signals, discriminating them from all other signals, and is one of the reasons for placing the charge at great depths.

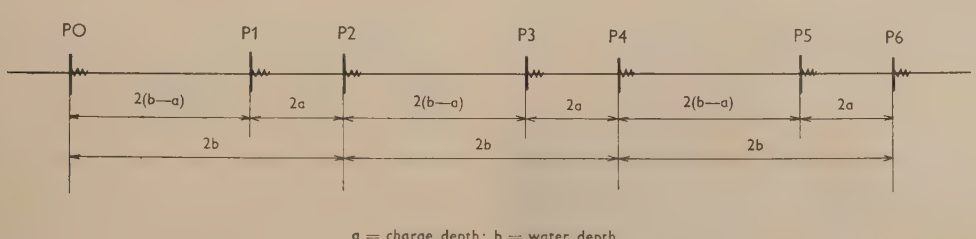

Fig. 9.

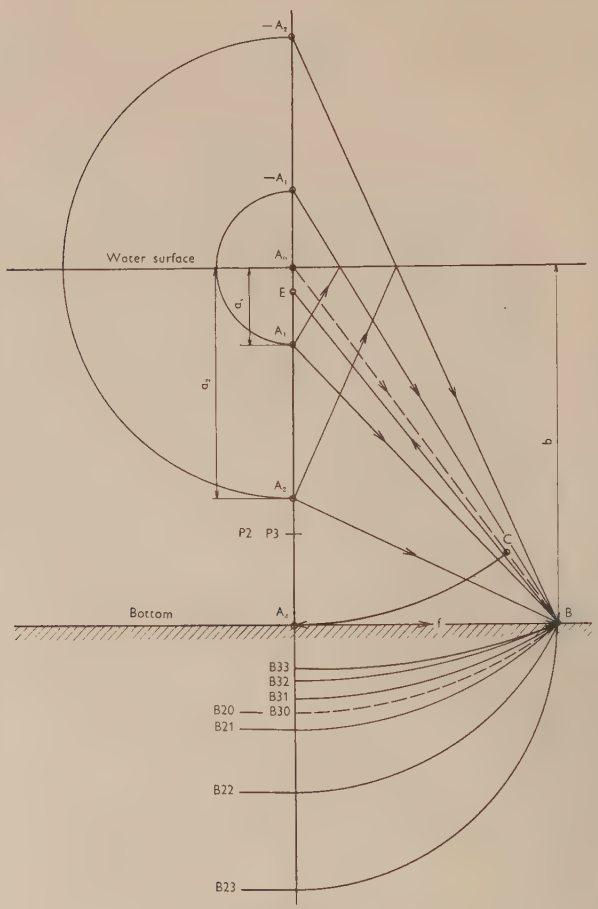

Fig. 10.

The time lag between the B and the corresponding P signals may also be calculated according to the formulae:

$$(B1 - P1) = \sqrt{(b-a)^2 + f^2} - (b-a) + \sqrt{(b-e)^2 + f^2} - (b-e)$$

$$(B2 - P2) = \sqrt{(b+a)^2 + f^2} - (b+a) + \sqrt{(b-e)^2 + f^2} - (b-e)$$

from which it will also be seen that these two time lags are equal only on the condition that $a = 0$.

Usually the B signals will be generated at many different points of the bottom, most of them located close to the perpendicular through the charge. In this case, the B signal acts as a prolongation of the corresponding P signal. It is apparent that the consecutive B signals will have different fine-structures.

It is also apparent that all B signals must lie after *P1* in the records i. e. the *BO* signal does not exist. On the other hand, it is quite possible for *B1* to follow after *P2* or even after *P3*.

The positions of the D signals in the record depend on the positions of the scattering layers in relation to the charge. (The hydrophone is assumed to be placed above the reflecting layers). The depth below the water surface of a layer may be denoted by d.

If then $d < a$, the shock wave penetrates the layer without affecting the recording, passes the receiver, generates the *P0a* signal and, after a reflection at the water surface, the *P0b* signal, is then reflected at the layer, and generates by passing the hydrophone, first the *D0a* and then the *D0b* signal. It is easy to see that the time lags (*D0a—P0a*) and (*D0b—P0b*) will both be equal to *2d*. The same law applies to the time lags between the following D signals and their corresponding P signals. An important property of the D signals is the existence of the *D0* signal. The same rule applies to all reflections from objects in the water.

If $a < d$ the diagram will be changed only in so far as an extra signal, denoted by D, will appear. The time lags (*Da—P0a*) and (*Db—P0b*) will both be equal to $2(d-a)$. It follows that *Da* must lie between *P0a* and *P1a*, but may sometimes come before *P0b*. The signal *D1* lies between *P0* and *P2*, and before *P1* if $d < (b-a)$; otherwise after *P1*.

The position of the G signal on the record is easily deduced from the preceding, as it may be said to be a D signal at the depth of d = a. Introducing this value in the preceding formulae, it is readily found that the time lags $((G0a-P0a) = (G0b) = 2d$ and that the G signal will appear before *P1* only if $2a < b$; otherwise between *P1* and *Pa*.

The D and G signals are the only signals that may appear earlier than *P1*.

Covered distance of	Charge located at		
	A0	A1	A2
P1	(A2−A0) + (A2−E)	(A2−A1) + (A2−E)	(A2−A2) + (A2−E)
B1	(B−A0) + (B−E)	(B−A1) + (B−E)	(B−A2) + (B−E)
B1−P1	(B10−A2) + (B−C)	(B11−A2) + (B−C)	(B12−A2) + (B−C)
P2	(A2−A0) + (A2−E)	(A2−R1) + (A2−E)	(A2−R2) + (A2−E)
B2	(B−A0) + (B−E)	(B−R1) + (B−E)	(B−R2) + (B−E)
B2−P2	(B20−A2) + (B−C)	(B21−A2) + (B−C)	(B22−A2) + (B−C)

The positions of the S signals in the record depend on the depth, denoted by c, of the reflecting horizons beneath the bottom. It is obvious that *S0* does not exist and that the time lags $(S1 - P1) = (S2 - P2) = (S3 - P3) = 2c$. These values are quite independent of the values of a and b. Since the velocity of sound in the sediment is not very well known, a nominal value of 1,500 m/sec will be used. This gives a nominal thickness of the sediment which has to be corrected by using the actual value of the sound velocity of the sediment, when obtained.

In the case of a stratified material just beneath the bottom, the S reflections may generate rather complicated signals, directly adhering to the corresponding P signals. Contrary to the B signals, the consecutive S signals will have a stable fine-structure. Unfortunately, they are most often obscured by the overlapping B signals.

Conditions for Non-overlapping Signals

It sometimes occurs that one signal is overlapped by another. In some cases this is unavoidable, for instance if B and S signals follow immediately after the P signals. Sometimes this drawback may be removed by changing the depths of the charge and the hydrophone i. e. by changing a and e. This method is particularly useful when an S signal has been overlapped by a P signal. The conditions for non-overlapping will now be discussed.

The overlapping capacity of a P signal depends on the length of the signal. The *P0* signal has an intrinsic duration caused by oscillations of the gas bubble. As mentioned in Chapter 3, the frequency and also the length decreases with decreasing charge and increasing depth. During a certain time which may be denoted by $2\,x_a$ the signal *P0a* thus blocks other signals and prevents them from appearing in the record. If the water surface were perfectly smooth, the signal *P0b* should be an exact replica of *P0a* and its blocking time $2\,x_b = 2\,x_a$. In general, $x_b > x_a$. If the depth e of the hydrophone is smaller than x_a the *P0a* and *P0b* will have the appearance of being only one signal *P0* with a blocking time of $2\,x = 2\,e + 2\,x_b$. In the same way, each P signal will have a blocking time of $2\,x$ which increases with its order number. The condition for non-blocking will then be that an S signal must not follow closer to a P signal than $2\,x$.

If the S signal is generated at a depth c beneath the bottom, this condition may be mathematically expressed by the formulae

$$nb + a > c > nb + x$$

$$(n + 1)\,b > c > nb + a + x$$

where $n = 0, 1, 2, 3$, etc.

The same formulae can also be made to apply to the D and G signals by substituting d and a, respectively, for c.

It follows from these formulae that x should be as small as possible, particularly if the sediment thickness c is small, as it is necessary that $c > x$ and thus a fortiori, $c > e$. For this reason it is sometimes advisable to lower the hydrophone to a greater depth, in order to locate *S1a* between *P1a* and *P1b*. The non-blocking condition will then be

$$e > c > x_a$$

and the minimum sediment thickness that can be measured will be x_a, which is much smaller than x.

Position Analysis

It follows from the preceding that it will in general be possible to identify the different signals by their positions in the diagram of signals. The different criteria will now be examined. After having identified and marked the P signals, an unknown signal, denoted by X1, X2, etc. may be identified according to the following scheme:

Position of signal	Criteria	Type of signal
Before *PO*	Position of the signal independent of P signals	A
Between *PO* and *P1*	(XO—PO) = 2a; 2a< b	G
	(XO—PO) = 2a; d + a< b	D
After *P1*	(X1—P1) = 2a; 2a >b	G
	(X1—P1) = (X2—P2) = = (X3—P3) Time lags independent of *a*	D, S
	(XI—P1) (X2—P2) (X3—P3) Time lags dependent of *a*	B

The criterion (S1—P1) = (S2—P2) etc. in the same record, will be denoted by the symbol 12 etc.

The criterion (S1—P1) in one record equal to (S1—P1) and/or to (S2—P2) etc. in another record from the same station, will be denoted by the symbols 1.12 or 1.2 etc.

Frequency Analysis

Hersey and Ewing (1949) have recorded repeated shots at the same station, using different band-pass filters each time, and have in this way found that high frequencies will be attenuated more than low frequencies during their passages through rock and sediment. This constitutes a good criterion for deciding whether a given echo comes from the bottom topography or from strata beneath the bottom, i. e. whether it is a *B* or an *S* signal. In this respect the *D* and *G* signals act in the same way as the *B* signals.

The introduction of magnetic recording makes this method of analyzing the records much easier, as the frequency composition of the different signals in the same record can be thoroughly examined in a laboratory, with more ease and more adequate instrumentation, after the expedition has returned home.

It may be pointed out that small sediment thicknesses do not attenuate high frequencies sufficiently to allow the use of this method. It should also be noted that the recording instrument, including the amplifier, may sometimes introduce an unintentional filtering, which has a particularly detrimental effect as regards low frequencies, as the *S* signals may then be suppressed, or at least weakened.

Typical Appearances of the Different Signals

The appearance of a signal may also be of use for the identification of its type. Under certain circumstances, this will be the only avaiable method, and therefore, some typical records will be shown and commented.

Symbols used on the records are:

No. 00 — shot and record number 00

St. 00 — station number 00

b — water depth in metres

The charge and its location are described by two figures, the first giving a symbol for the weight, the second the depth in metres. The symbols for the weights are:

0 — detonator No. 8

1 — hydrostatic fuse (4 gr.) + 1x170 gr. of TNT = 174 gr

2 — hydrostatic fuse (4 gr.) + 2x170 gr. of TNT = 344 gr

etc.

Impl. — implosion bomb

Thus, 0/30 means a detonator at 30 m., 4/2,500 means 684 gr. of TNT at a depth of 2,500 m. below the surface.

Time is marked on the oscillograms by an RC generator of 15 c/s i. e. the time from peak to peak is equal to the travel time of 100 m. in water. This frequency had decreased a few percent during the later part of the expedition.

Spurious signals may sometimes obscure the records, but generally they have a characteristic appearance, which reveals their origin. Mostly, they are caused by electrical noises which may be suppressed by a careful screening of the cables. This was so successfully done on board the ALBATROSS that there was no need to stop electric motors of auxiliary machines. The only source of noise that could not be tolerated was the radio, which could not be allowed to transmit while the measurements were being made. Acoustic noises from above the water surface seldom caused any disturbances. To chip rust was of course not allowed during the measurements, but not even a strong wind and a choppy sea disturbed the recordings, as shown by No. 74 taken at a wind velocity of 18 m/sec and a state of sea of No. 6 in the Douglas sea scale. Underwater noises are of course much more disturbing. The ship's screw was completely disastrous when rotating, and had to be stopped during measurements.

The P0 signals will change their appearance with the size of the charge and its depth below the surface, but still more with the type of hydrophone and with the recording instrument.

Most hydrophones produce a signal which has an amplitude proportional to the peak pressure P_m of the shock wave. For TNT charges in a free water space, this pressure may be calculated according to the formula:

$$P_m = 2.25 \times 10^4 \, W^{1/3} / R^{1.3} \text{ lb/in}^2$$

where W is in lbs, and R in ft.

Some hydrophones respond in proportion to the impulse, which for TNT charges may be calculated as

$$I = 2.18 \, W^{2/3} / R^{2.12}$$

When recording with an oscilloscope, the *P0* signal will seldom be of shorter duration than a travel time of 200 metres in water, which restricts the minimum thickness of sediments to be measured to about 100 m. An examples is shown in No. 36.

When using a wire recorder, the conditions are much better. Nos. 392, 393a, 395, and 396 illustrate the possibility of separating the signal *P0a* from *P0b* at a hydrophone depth of 20 m. By increasing the recording speed, as shown in No. 393b, it is possible to record sediment layers of a thickness of less than 10 m.

If the TNT charge is replaced by an implosion bomb, the signal is very short and sharply defined, as shown in Nos. 326a and b at two different recording speeds. The bomb collapsed at a depth of 1,760 m.

The amplitude of *P0a* is generally larger than that of *P0b* (Nos. 326, 392, 393). In some cases (No. 396) *P0b* is slightly larger, and in other cases (No. 395) considerably larger than *P0a*. This observation has also been made by LIEBERMANN (1948 b), who found that the shock wave will be focused by surface waves in 10 % of all cases, giving an apparent coefficient of reflection greater than 1. The state

of the sea was No. 3 for shots Nos. 395 and 396 and No. 2 for shots Nos. 326, 392 and 393 in the Douglas sea-scale.

Quite frequently the signals will be prolonged by reflections from scattering layers just beneath the water surface (D signals) as will be shown in the following.

The P1 signals are generated by reflections at the bottom and may thus be expected to have varying amplitudes and appearances.

Measurements by LIEBERMANN (1948 a) at different stations in the Atlantic, not far from Woods Hole, have given as results the following values of the coefficient of reflection:

mud	0.00—0.20
mud-sand	0.20—0.40
sand-mud	0.40—0.60
sand	0.40—0.85
stony	0.50—0.85

The duration of the *P1* signals should be exactly the same as that of the *P0* signal, if the bottom would act as a plane specular reflector. Actually, they will almost always be prolonged by side reflections from the bottom and/or by reflections from layers beneath the bottom i. e. by *B* and *S* signals.

It is frequently found that the relation between the amplitudes of *P1a* and *P1b* differs from that of *P0a* and *P0b* in the same record (No. 392). This is easily understood, as the water surface has had time enough to change its focusing properties during the time elapsed between the reflections of the *P0* and the *P1* signals.

The P2, P3, and following primary signals have the same principal appearance as the *P1* signal, but are usually modified by extra reflections and sometimes also prolonged by adhering *B* and *S* signals.

The A signals were, in the beginning, misinterpreted as electrical noises, and not recognised as coming from bathy-pelagic animals. Otherwise it had been very easy to discriminate between these two types of signals, by taking the hydrophone out of the water, when A signals must disappear, but not electric noises. It is now quite certain that many of the signals recorded emanate from marine life, as shown by LOYE and PROUDFOOT (1946), EVEREST, YOUNG, and JOHNSON (1948), and others.

There are three reasons for interpreting these signals as animal noises:

1. They have a characteristic appearance, different from known electric and acoustic noises, and they may be classified into three types: High-frequency pulses with constant repetition frequency, high-frequency pulses with irregular repetition frequency, and low-frequency noises. The *first type* is very probably generated by single individuals, the *second type* might be interpreted as the noise from a school of animals, but the *third type* is obscure. Possibly, these signals have been generated by splashes from the movement of some large animals. The *first type* may be illustrated by Nos. 225, 141 and 96, which are recorded by the oscilloscope, and No. 400, which is recorded by the wire recorder.

The second type may be illustrated by Nos. 290, 297 and 306 and the *third type* by Nos. 36 and 91. The criterion that this *A* signal, lying between *P1* and *P2*, is not a *B*, *D*, or an *S* signal lies in the fact that it is not repeated in position due to these signals.

2. They very often appear as doublets (*Aa* and *Ab*) with a time lag between the two components, corresponding to the travel time from the hydrophone to the water surface and back again, as will be the case if the source is located under the hydrophone. The general condition is $0 \leq (\mathrm{Ab}-\mathrm{Aa}) \leq (\mathrm{P0b}-\mathrm{P0a})$ where the left limit corresponds to a source located at the surface, and the right limit, to a source located on the perpendicular through the receiver and below it. This may be illustrated by No. 391. The distance between *Aa* and *Ab*, indicated in the record, corresponds

to a travel time of 2×17 metres in water. The hydrophone was nominally placed at a depth of 20 m. but the drift of the ship with stopped propellers has often been found to decrease the depth by a few metres.

3. The noises very often stop immediately at the shot, and then reappear after a few seconds. In No. 400 the silence lasted one and a half second, and then the noise started anew with a somewhat higher repetition frequency, of 14 p/s. In other records a silence of several seconds has been observed.[1])

The B signals, as generated by the topographic relief of the bottom, have a very variable appearance. Sometimes their duration is very long. If the bottom is much undulated and the charge located well above the bottom, even the following primary signals may be overlapped. No. 102 illustrates such a case, where the bottom had the highest degree of ruggedness, (No. 3) as recorded by the fathometer. The duration is decreased by locating the charge closer to the bottom, as may be seen in No. 103, from the same station and with the same charge but at a depth of 50 m. above the bottom only, instead of 2,180, as in No. 102. For the same reason the *B2* signal in the same record is much longer than the *B1* signal. Accordingly, the shortest duration possible will be obtained by placing the charge in the uppermost layer of the sediment, as proposed by Professor PETTERSSON and demonstrated by No. 333. The joint signal *P01* has a duration corresponding to a travel time in water of 2×60 m. only. For this reason, an *S1* signal from a horizon a little less than 80 nominal metres beneath the bottom has not been overlapped. The charge was 510 g of TNT. A smaller charge would have given a still shorter joint signal *P01*.

The D signals, as generated by reflections from layers or objects located between the water surface and the bottom, have an individual appearance. Sometimes they emanate from distinct strata, as exemplified by Nos. 26, 335, and 413. In No. 335, the signals *P0a* and *P0b* are well separated. The depth of the hydrophone was nominally 80 m but the record shows that it was in reality only 40 m. This is due to the drift of the ship under a wind of 8 m/s with stopped propellers. The charge, 684 gr of TNT, was located 350 m below the surface, which gives a bubble pulse time of 13 ms. The oscillations of the gas bubble with this frequency can be observed in all the primary signals. Two *D* signals, one from a depth of 75 m, $D0_1$, has its components *a* and *b* well separated, and another from a depth of 150 m., $D0_2$, is also split up into two components, *a* and *b*. These *D* signals are repeated after the *P1* and *P2* signals, and could easily have been taken for *S* signals if *P0* were unknown.

In shot No. *413*, the charge, 6,294 gr. of TNT, was located at a depth of 2,490 m. The

[1]) During a recent visit to Cambridge, I was informed by Dr. NEEDHAM that sounds of fishes have been detected and used by Chinese fishermen. This is an extract from »Science and Civilisation in China», a forthcoming book by JOSEPH NEEDHAM, Cambridge University Press, Cambridge, 1954 which the Author kindly put at my disposal.

»One of the most curious later applications of Chinese vibration detectors was the use of an instrument by the fishermen of northern Fukien for obtaining audible warning of the approach of »runs» or »shoals» of fish. At San-Tu-Ao bay, for example, great quantities of yellow fish are caught at those times of the year when they come up to brackish water to spawn. When the fishermen suspect that a run is about to take place, they take a section of bamboo about 2 inches in diameter and 5 feet long, plunge it in the water to a depth of $3\frac{1}{2}-4$ ft. and apply their ears to the upper orifice beside the boat. Western observers present have heard sound like a confused distant rumble when the shoal was said by the fishermen to be about a mile away, an estimate which was confirmed by the catch in due course. It is to be presumed that prolonged experience would confer considerable skill in making the estimates. Although no references to this practice have been found in the Chinese literature, there is no reason to doubt its traditional character, and if it may be assumed to be an indigenous technique, it anticipated in its primitive way the modern use of echo-sounding in the detection of shoals of fish.»

N. B. The information in this paragraph is based on a memorandum kindly provided to Dr NEEDHAM by Mr HORATIO HAWKINS, formerly a Commissioner in the Chinese Customs Service. Similar techniques are known and used in Malaya.

bubble pulse time in this case is 5.8 ms. Three distinct *D0* reflections from 60, 90, and 130 m depths are seen, followed by protracted signals from depths between 150 and 350 m and more. The *D1* and *D2* signals are overlapped by *B* signals.

Sometimes the scattering objects seem to be evenly distributed in a region between two horisontal surfaces, which may be illustrated by Nos. 366, 384, and 421 taken at 19 00h, 22 20h, 14 20h.

The appearance of the *D* signals depends to some extent also on the charge and its location, as shown by comparing Nos. 421 and 422, taken at the same station (St. 400) and the same charge (684 gr.) but the first shot at a depth of 790 m and the second at 2,850 m. In the first case reflections which are larger and from deeper layers are recorded, quite naturally, as the charge in the second case is located more than three times as far from the surface as in the first case.

A very peculiar *D* signal is shown in No. 55 S, taken on May 12th, 1946, during a preliminary expedition with the »Skagerak», in the Mediterranean. This signal has been reflected from the KULLENBERG piston core sampler, just then on its way down, and at a depth of 1,445 m below the surface. The reflecting surface, principally the upper surface of the weights, was of the magnitude of some 15 dm^2 only. The hydrophone was at that time of the quartz-crystal type previously described.

The *G signal* has a characteristic appearance. As example No. 30S, taken from the »Skagerak» on April 25th, 1946, is shown. The charge was 450 gr. of TNT at a depth of 270 m. Another example is shown in No. 64 from the ALBATROSS. The charge was 174 gr. of TNT at 575 m. In the latter case the amplification used was only 1/100 of the maximum capacity, but nevertheless quite sufficient, in spite of the fact that the shock wave had had to travel a distance of 1,700 m before reaching the hydrophone.

The *S signals*, as generated by reflections from sub-bottom strata, are as changing as the structure of the sediment itself. This may be illustrated by Nos. 34, 66, 154, and 183, recorded by the oscilloscope, and Nos. 392, 393, and 412, by the wire recorder.

A very peculiar type of *S* signals, found in a limited area between Hawaii and Mindanao, is shown in Nos. 194 and 195. These signals, very likely indicate a watery, homogeneous sediment layer, covering rock or a steady sediment. This interpretation is strengthened by the interesting fact that the fathometer did not record any bottom reflections at all at this station. The *S* criterion is a very clear 12.12 i. e. (P1—S1) = (P2—S2) on two records taken with different charge depths (in this case 2,500 and 4,500 m.) If the reflections had come from elements of topography in the vicinity of the station, the four distances (P—X) on the records, now being equal (2×150 m.), should have had different values.

Signals of this type have also been observed by HERSEY and EWING (1949) who have called them type F (forerunner).

Results

Primary Experimental Data

During the expedition, a total of 415 explosions from shots of TNT charges and 3 implosion bombs were recorded at 193 stations.

The distribution of weights of the charges was:

Number of shots	Weight in grammes
19	1
12	174
25	514
268	684
55	854
21	1024
28	1534
7	6294

TABLE 4. Shot list.

Shot No.	Station No.	Position		Water depth m	Bottom condition	Charges
		° ′	° ′			
29—32	12	N 31 27	W 23 19	5400	0	0/40 4/500 4/2500 4/4500
33—34	14	N 30 46	W 25 15	5380	0	4/500 4/2500
35—36	15	N 30 46	W 25 25	5410	0	4/500 4/2500
37—38	16	N 26 25	W 34 00	5520	1	0/40 4/500
39—40	17	N 25 15	W 36 21	5750	1—2	4/500 4/2500
41—42	18	N 25 07	W 36 20	6100	2	4/2500 4/4500
43—45	20	N 22 49	W 41 26	5900	1	1/500 4/4500 4/2500
46	21	N 23 00	W 45 10	1520	3	1/500
47	22	N 21 24	W 46 24	3300	3	1/500
48—50	23	N 20 01	W 49 18	4210	3	0/60 1/500 4/2500
51—52	24	N 18 23	W 52 57	4210	2—3	0/40 0/40
53—55	25	N 17 03	W 56 18	5700	2	4/500 4/2500 4/4500
56—58	26	N 16 21	W 58 15	5560	0	4/500 4/2500 4/4500
59—61	27	N 16 14	W 58 29	5500	0—1	4/500 4/2500 4/4500
62—63	28	N 14 53	W 61 31	2660	2—3	4/500 4/2500
64—65	29	N 14 54	W 63 65	2630	2	1/500 4/2500
66—67	30	N 14 25	W 65 55	3760	0	4/2500 4/4500
68—69	31	N 14 27	W 66 13	5030	0	4/2500 4/4500
70—71	32	N 14 25	W 66 26	5060	0	4/2500 4/4500
72—73	33	N 14 10	W 68 20	5030	1—2	4/2500 4/4500
74—75	36	N 14 15	W 70 36	4060	0	4/2500 4/2500
76—77	38	N 14 15	W 71 02	3970	1	4/2500 4/2500
78—79	39	N 11 34	W 78 41	3580	0—1	4/500 4/2500
80—81	40	N 11 25	W 78 47	3400	0	4/500 4/2500
82—83	42	N 07 00	W 78 54	2875	1	4/500 4/2500
84—85	43	N 06 09	W 80 26	3115	1	4/500 4/2500
86	44	N 05 50	W 80 53	2940	1	4/2500
87—88	45	N 05 15	W 81 42	3860	2—3	4/500 4/2500
89	46	N 04 41	W 82 25	3470	2—3	4/2500
90—91	48	N 01 45	W 86 14	2850	3	4/500 4/2500
92—93	52	S 02 52	W 89 50	3210	1	4/500 4/2500
94—95	54	S 02 54	W 92 15	3580	1	4/500 4/2500
96—97	55	S 02 44	W 92 43	3640	2	$4_2$500 4/2500
98—99	56	S 01 33	W 92 19	3290	1—2	4/500 4/2500
100—101	58	N 01 04	W 93 20	2880	1—2	4/500 4/2500
102—103	59	N 02 10	W 95 30	2530	3	4/500 4/2500
104—105	61	N 03 20	W 97 53	3190	1	4/500 4/2500
106—107	62	N 04 32	W 100 06	3380	2	4/500 4/2500
108—109	63	N 05 42	W 101 41	3200	2—3	4/500 4/2500
110—111	65	N 06 21	W 103 42	3330	2—3	4/500 4/2500
112—113	66	N 06 55	W 104 46	3530	3	4/500 4/2500
114—115	67	N 07 38	W 106 17	3760	3	4/500 4/2500
116—117	69	N 08 22	W 108 00	3800	2—3	4/500 4/2500
118—119	71	N 09 26	W 109 55	3780	2	4/500 4/2500
120—121	72	N 10 35	W 112 05	3760	3	4/500 4/2500
122—123	73	N 11 25	W 113 48	—	2—3	4/500 4/2500
124—125	75	N 12 18	W 115 33	4260	2—3	4/500 4/2500
126—127	76	N 13 20	W 117 58	4260	2	4/500 4/2500
128—129	77	N 14 13	W 120 25	4430	2—3	4/500 4/2500
130—131	78	N 15 40	W 123 21	4360	1	4/500 4/2500
132—133	80	N 17 46	W 126 51	4650	2	4/500 4/2500
134—135	81	N 15 34	W 127 11	4826	3	4/500 4/2500
136—137	82	N 13 19	W 127 25	4753	2—3	4/500 4/2500

Shot No.	Station No.	Position		Water depth m	Bottom condition	Charges
		° ′	° ′			
138—139	85	N 11 30	W 127 37	4914	2—3	4/2500 4/4500
140—141	86	N 09 50	W 128 13	4645	2	4/500 4/2500
142—143	87	N 08 25	W 128 48	4770	1—2	4/500 4/2500
144—145	88	N 06 44	W 129 28	4460	2—3	4/500 4/2500
146—147	89	N 04 49	W 130 52	4500	—	4/500 4/2500
148—149	90	N 03 05	W 133 06	4360	2—3	4/500 4/2500
150—151	92	N 01 35	W 134 57	4570	1	4/500 4/2500
152—153	93	S 00 06	W 135 58	4470	1	4/500 4/2500
154—155	94	S 03 00	W 136 26	4520	1—2	4/500 4/2500
156—157	95	S 05 37	W 137 53	4340	2	4/500 4/2500
158—159	97	S 12 00	W 144 20	4960	3	4/2500 4/4500
160—161	98	S 13 03	W 146 01	5060	0	4/500 4/2500
162—163	99	S 14 12	W 147 37	3900	0	4/500 4/2500
164—165	100	S 15 49	W 148 53	4270	1	4/500 4/2500
166—169	102	S 13 25	W 149 30	4630	1—2	4/500 4/2500
170—171	104	S 11 15	W 150 30	5030	3	4/2500 4/4500
172—173	105	S 07 38	W 152 53	5020	2—3	4/2500 4/4500
174—175	106	S 04 04	W 152 53	5170	2—3	4/500 4/2500
176—177	110	S 00 20	W 151 31	4470	1	4/500 4/2500
178—179	112	N 00 20	W 150 56	4430	1	4/500 4/2500
180—181	114	N 03 45	W 149 44	5140	1	4/2500 4/4500
182—183	118	N 08 17	W 148 41	4940	1	4/500 4/2500
184—185	127	N 14 28	W 164 59	5400	2—3	4/2500 4/4500
186	128	N 12 16	W 166 48	5080	2	4/2500
187—188	129	N 10 10	W 168 02	5360	2—3	4/2500 4/4500
189—190	130	N 08 40	W 169 28	5440	2	5/2500
191—192	131	N 06 21	W 171 52	5800	2—3	4/500 4/2500
193	132	N 05 34	W 172 12	5450	2	5/2500
194—195	134	N 04 02	W 172 19	5560	3	4/4500 5/2500
196—197	136	N 02 23	W 173 50	5560	3	4/4500 5/2500
198—199	138	S 02 37	W 177 45	5770	2	5/500 4/2500
200—201	139	S 02 48	W 178 57	5480	2—3	5/500 4/2500
202—203	140	S 03 21	E 174 12	4920	2—3	4/4500 5/2500
204—205	141	S 02 50	E 171 18	4130	0	5/500 5/2500
206—207	142	S 01 20	E 167 23	3970	0	5/500 5/2500
208—209	143	S 00 09	E 165 26	4410	1—2	5/500 5/2500
210—211	144	N 00 34	E 159 59	2890	1	5/500 5/2500
212	145	N 00 52	E 157 04	2200	1	5/500
213—214	148	N 01 40	E 152 37	3770	1	5/500 5/2500
215—216	149	N 02 20	E 149 41	6080	—	5/500 4/2500
217—218	150	N 02 09	E 146 52	4520	1	5/500 5/2500
219—220	151	N 02 11	E 145 47	4620	1—2	5/500 5/2500
221—222	153	N 02 25	E 144 04	4525	1	5/500 4/2500
223—224	154	N 02 36	E 142 32	3750	1	5/500 5/2500
225—226	155	N 02 38	E 139 34	4275	2	5/2500 5/500
227—228	159	N 04 26	E 130 21	4980	—	4/4500 5/2500
229—234	160	N 04 43	E 128 07	7710	2	9/6500 4/6500 9/4500 4/4500 9/2500 5/2500
235—237	162	N 05 23	E 127 48	8390	2—3	4/2500 1/20 1/20
238—239	163	N 05 23	E 127 46	8880	2—3	9/4500 9/6500
240—241	164	N 05 23	E 127 46	8690	2	9/4500 9/6500
242—243	169	S 02 44	E 125 22	5325	1	4/4500 5/2500
244—245	170	S 04 48	E 123 49	4710	3	5/2500 9/2500
246—247	171	S 07 00	E 123 04	3120	3	5/2500 9/2500
248	172	S 07 58	E 121 45	4375	2—3	5/2500
249—250	174	S 07 46	E 120 20	5080	1—2	5/500 9/4500

Shot No.	Station No.	Position		Water depth m	Bottom condition	Charges
		° ′	° ′			
251—252	185	S 10 07	E 108 56	6875	3	4/4500 5/2500
253—254	186	S 10 46	E 106 16	5735	3	4/4500 5/2500
255—256	190	S 11 28	E 102 14	5450	1—2	4/4500 5/2300
257—258	194	S 11 22	E 99 41	5440	2	4/4500 5/2500
259—260	197	S 11 11	E 96 07	4900	3	4/2500 5/4500
261—262	199	S 11 33	E 91 26	5020	2—3	4/4500 5/2500
262—264	205	S 04 47	E 88 18	5050	0	4/4500 5/2500
265—266	208	N 01 56	E 88 12	4300	1	5/2500 4/2500
267—268	209	N 02 45	E 86 53	4290	0	9/500 9/2500
269—274	210	N 03 49	E 84 46	4150	0—1	4/500 9/500 4/2500 9/2500 4/2500 1/30
275—276	214	N 02 18	E 76 02	3750	1—2	5/2500 4/2500
277—278	216	N 00 04	E 74 53	4280	1	4/2500 4/2500
279—280	218	S 00 57	E 73 56	2850	1—3	5/500 4/2500
281—282	219	S 01 12	E 72 00	4390	1	4/2500 4/2500
283—284	221	S 01 20	E 68 20	3650	3	5/2500 4/2500
285—286	223	S 01 19	E 66 16	4390	1	5/2500 4/2500
287—288	224	S 01 20	E 64 00	4440	—	5/2500 4/2500
289—290	225	S 01 22	E 63 38	4740	—	5/2500 4/2500
291	226	S 01 37	E 61 00	4660	—	5/2500
292	227	S 02 13	E 58 43	4380	—	4/2500
293—294	228	S 03 18	E 56 47	4080	—	5/2500 4/2500
295—296	229	S 02 48	E 55 35	3600	2—3	1/40 1/45
297	230	S 02 18	E 55 33	4400	—	4/2500
298—299	231	S 00 23	E 54 30	4850	0	4/4500 5/2500
300—301	233	N 02 22	E 53 09	5120	0	4/4500 5/2500
302—303	234	N 04 28	E 52 48	5130	0	4/4500 5/2500
304—305	235	N 07 14	E 52 49	5130	0	4/4500 5/2500
306—307	238	N 08 40	E 52 52	5060	0	4/4500 5/2500
308	239	N 10 06	E 52 45	4160	1	5/2500
309—310	287	N 36 13	E 17 28	3610	2—3	5/500 4/2500
311—312	289	N 37 33	E 15 24	2050	1—2	4/500 4/1000
313—314	291	N 40 05	E 13 45	1710	2	4/500 4/1000
315	292	N 40 30	E 13 43	1270	2	5/500
316—317	295	N 40 13	E 12 22	3610	3	9/1000 9/2500
318—319	297	N 43 34	E 07 43	2230	1	4/500 4/1000
320—322	298	N 42 38	E 07 09	2665	1	4/500 4/1000 4/2500
323—324	299	N 42 17	E 06 57	2720	0	impl/2080 4/1980
325—327	300	N 40 05	E 05 34	2830	0	3/— impl/1760 3/2540
328—329	302	N 38 21	E 03 27	2760	1—2	4/500 4/2500
330—332	303	N 37 26	E 01 05	2720	1—2	4/500 impl/— 4/2500
333	304	N 35 57	W 02 02	1740	3	3/1740
334—336	305	N 35 55	W 02 20	1370	1	3/1370 4/500 4/1000
337	311	N 33 29	W 11 03	4390	0—1	3/1380
338—339	312	N 29 55	W 17 32	4340	1	3/— 3/1610
340—341	315	N 27 27	W 19 43	4360	1	3/2620 3/3720
342	316	N 25 29	W 21 37	4670	1	3/3530
343	318	N 23 13	W 23 01	4900	—	3/—
344	319	N 22 31	W 23 28	4930	1	3/4110
345	320	N 20 21	W 20 37	3840	0	3/2680
346	323	N 17 57	W 21 03	3120	0—1	3/3120
347—348	325	N 15 53	25W 27	4280	0	4/1000 4/2500
349—350	326	N 13 37	W 25 55	4820	0	4/1000 4/2500
351	330	N 07 53	W 24 43	4960	0—1	3/2660
352—353	332	N 05 45	W 21 43	3560	1—2	6/1000 3/2640

Shot No.	Station No.	Position		Water depth m	Bottom condition	Charges
		° ′	° ′			
354—355	334	N 03 12	W 20 28	4620	—	4/1000 3/—
356—357	335	N 02 06	W 20 07	5110	1—2	4/1000 3/4360
358	336	N 00 45	W 18 52	5040	—	3/—
359—362	339	S 00 07	W 18 12	7240	1	9/2500 9/6500 3/3630 3/3260
363	343	N 01 10	W 19 50	4330	2	3/2660
364—365	345	N 00 30	W 25 38	3290	1	9/1000 9/2500
366—368	347	N 00 27	W 27 45	3740	0	9/1000 9/2500 3/3740
369—371	351	N 00 39	W 32 10	3950	2	9/2500 9/1000 3/3950
372—373	353	N 00 16	W 33 40	4580	0	4/1000 4/2500
374—376	354	N 00 06	W 34 41	4570	0	4/1000 4/2500 3/2660
377—378	356	N 02 10	W 39 06	4500	0	4/1000 4/2500
379—380	359	N 06 17	W 43 20	4550	1	9/1000 9/2500
381—382	361	N 08 15	W 46 30	4570	0	4/1000 4/2500
383—385	362	N 11 44	W 51 09	5020	0	3/2750 4/1000 4/2500
386—387	364	N 12 54	W 52 55	5130	0—1	4/1000 4/2500
388—390	365	N 14 32	W 55 05	5480	0	4/1000 4/2500 4/4500
391—393	366	N 15 44	W 56 50	5300	1—2	4/1000 4/2500 4/4500
394—396	367	N 16 51	W 58 21	5820	2	4/1000 4/2500 4/4500
397—399	373	N 28 25	W 61 05	6020	2	4/1000 4/2500 4/4500
400—402	376	N 30 29	W 56 07	5620	0	4/1000 4/2500 4/4500
403—404	381	N 34 06	W 46 12	4450	1	4/1000 37/2500
405—407	382	N 34 57	W 44 16	4290	1	4/1000 4/2500 37/2500
408—410	385	N 37 37	W 41 41	4990	1—2	4/1000 4/2500 36/2500
411—413	386	N 40 32	W 38 17	4110	2	4/1000 4/2500 37/2500
414—416	388	N 40 40	W 34 58	4060	1—2	4/1000 4/2500 37/2500
417—418	390	N 41 08	W 31 50	2630	2	4/1000 3/2630
419—420	394	N 42 16	W 26 30	3120	1	4/1000 4/3000
421—424	400	N 43 04	W 19 40	5980	2	4/1000 4/3000 4/4500 37/3000
425—427	401	N 43 24	W 18 59	4280	2	4/1000 3/3930 37/3000
428—429	402	N 47 41	W 12 43	—	1	4/1000 3/—
430—432	403	N 48 00	W 11 59	3630	1	4/— 3/3630 4/1000

The distribution of depths of the charges was:

Number of shots	Depth in metres
24	10—85
1	250
92	500
36	1000
185	2500
4	3000
46	4500
4	6500
17	1380—4360
6	at the bottom

After some experimenting, it was found most favourable to place the hydrophones, two at a time, at a depth of 20 m below the water surface. This depth has been used throughout all shots from No. 29 to No. 432 with the exception of Nos. 48—50 for which one of the two hydrophones was lowered to 40 m. and of Nos. 328—336 for which it was lowered to 80 m.

The following principal data are given in TABLE 4: Shot Nos., Nos. of stations where shots were made, their positions, water depths in metres as measured by the fathometer, bottom conditions, and weights and depths of the charges. The bottom condition is denoted by a figure giving the unevenness as estimated from the diagrams of the fathometer, according to the scale:

0 — smooth

1 — rather smooth

2 — rather rugged

3 — very rugged

The estimate, which has kindly been made by Dr. Fritz Koczy, has rendered valuable service in connection with the identification of *B* signals.

Animal Noises (A Signals)

Animal noises have very frequently been recorded. Distinct *A* signals have been found in 112 out of 415 records, or in more than 25 % of all the records made during the expedition. As already mentioned, the signals may be classified into three types.

Signals of the *first type* have been found in 29 records. The lowest repetition frequency so far found was 1.8 pulses/sec. as seen in No. 225. The only signals of this type in this record are the seven pulses which lie between the signals *P1* and *P3*. No. 141 shows some pulses which are repeated with a frequency of 4 p/s, lying between *P0* and *P2*, the only ones of this kind in the record. Just before *P3* some weaker pulses with a repetition frequency of 14 p/s may be seen. No. 96 demonstrates a train of pulses with a repetition frequency of 14 p/s lying between *P2* and *P3*.

TABLE 5 gives the Nos. of the stations where signals of this type have been observed, their repetition frequencies in pulses per second, and the local time at which the shots were made.

Signals of the *second type* have been found in 75 records. Strong signals of this type have been observed at the following stations: 26, 28, 92, 102, 106, 138, 162, 185, 210, 219, 221, 224, 225, 228, 230, 234, 235, 238, 287, 291, 292, 297, 299, 303, 304, 305, 311, 312, 315, 319, 323, 326, 332, 339, 361, 362, 366, 367, and 373. Weaker but quite recognizable signals of this type have been observed at the following stations: 26, 27, 33, 36, 43, 54, 61, 77, 80, 81, 90, 95, 100, 106, 114, 131, 139, 229, and 373.

TABLE 5. Animal noises with regular repetition frequency.

Shot No.	Station No.	Local time	Pulses pr. sec.	Shot No.	Station No.	Local time	Pulses pr. sec.
67	30	09.24	12	163	99	10.20	13
70	32	23.15	9	187	129	17.35	16
71	32	23.19	8; 15	188	129	17.35	20
77	38	13.25	14	194	134	10.45	12
79	39	10.16	14	213	148	13.10	4
92	52	13.45	13	225	155	11.35	1.8
93	52	13.45	14	258	194	11.15	9
96	55	19.00	14	264	205	16.55	9
97	55	19.00	14	300	233	19.45	14
132	80	09.15	13				
141	86	11.45	4; 11; 14	360	339	19.00	28
142	87	15.20	11	361	339	19.00	29
144	88	10.30	12	391	366	19.40	31
145	88	10.30	12	396	367	17.15	12
153	93	11.30	12	400	376	09.30	14

Signals of the *third type* have been found in 8 records at the following stations: 23, 26, 27, 48, 130, 229, 231.

Scattering Layers in the Water (D Signals)

Reflections from scattering layers in the water are very common. During the first part of the expedition, when an oscilloscope was used for recording purposes, the signal *P0* was taken as a warning to start the paper of the oscilloscope and could for this reason not be recorded. An exception was the ten shots where the charge was located at a depth of less than 60 m. and could thus be fired through a cable.

The introduction of the wire recorder made it possible to record the signal *P0*. An examination of the 77 records, presenting *P0* signals, has shown clear D signals in 55 of them. For this reason it is easier to give the records where no prolongation of the *P0* signal through *D* signals was found. They were: Nos. 339, 341, 344, 345, 348, 350, 351, 353, 357, 360, 363, 364, 376, 371, 387, 392, 393, 395, 396, 401, 402, 412.

Side Reflections from the Bottom Topography

In the shot list, TABLE 4, the ruggedness of the bottom is given as estimated from the fathometer recordings. There must, of course, be a strong correlation between this estimated ruggedness and the *B* signals but not necessarily a perfect one, as the fathometer reveals the »macroscopical» and the *B* signals the »microscopical» nature of undulations of the bottom. In order to find out this correlation, the records, heavily disturbed by *B* signals, have been compared to the different degree of unevenness given in TABLE 4, and the percentage computed, as shown in TABLE 6. It may be seen that only 10 % of the records from stations with the unevenness 0 have been disturbed by *B* signals, against 91 % of the records from stations of unevenness 3. The correlation is thus very strong but not perfect.

TABLE 6. Correlation between state of bottom ruggedness and disturbances by B signals.

Degree of ruggedness	Total number of stations	Disturbed by B signals	
		Number of stations	%
0	33	3	10
0—1	7	1	14
1	44	16	36
1—2	21	8	38
2	28	16	57
2—3	27	21	79
3	22	20	91
	182	84	46

Also 8 stations for which no bottom condition is stated.

Sub-bottom Reflections

By using the position analysis described in the preceding, the records have been scrutinized and the *S* signals identified. The result is given in TABLE 7, where the nominal thickness of the layers are given in metres i. e. the thickness is calculated on the assumption that the wave velocity was 1,500 m/s.

TABLE 7. List of sub-bottom reflections.

Station	Horizons below bottom	Criteria
Madeira-Atlantic Ridge		
14	1550, 2200, 3475	12.12 — 1.12 — 1
15	325, 550, 2400	123 — 12 — 1(1)
Atlantic Ridge-Martinique		
26	300	12.12
27	300	1.12
Carribean Sea		
30	200, 350	1.12 — 12.12
31	400	11
32	350, 450	12 — 12
36	650, 950	11 — 11
39	150	1.12
Panama-Galapagos		
43	100, 200, 420	12.12 — 12.12 — 1.2
52	260, 340	12.12 — 12.12
54	260	12.12
55	350	12.2
56	200, 270	12.12 — 12.12
Galapagos-18° N		
58	275, 420	12 — 12
61	210	12
71	120	134
80	650	12
18° N-Marquesas		
87	225	12
89	100	12.12
92	250	12.1
93	200	12.12
94	150	12
Marquesas-Tahiti		
98	150	1
99	160 (forerunner)	1.1
100	165	1.12
102	135	12.1 — 12.12
106	50 (forerunner)	1.2
110	60	12
118	190	12.123
Hawaii-Mindanao		
132	70 (forerunner)	12
134	140 (forerunner)	12.12
136	100 (forerunner)	12.12
138	20 (forerunner)	1.12
141	200	123.123
142	140	12
143	95, 200	12.12 — 12.1
148	190	12.12
151	145	12.1

Station	Horizons below bottom	Criteria
Mindanao-Java		
169	95	12
171	110	12
174	160	12.12
Java-Ceylon-Seyshells-Red Sea		
210	100	1.12
225	75, 130	1234.12 — 1234.12
226	75	123
228	120	12.12
231	90	12
Tanger-Romanche Deep-along the Equator		
315	100	12.12
316	60	12
326	80	12.12
353	100	1.1
Equ. 35° W-St. Thomas-London		
361	150	1.1
366	60	12.12.12
386	100	12.12
400	100	12.12.1.1

In the table, the criteria are also indicated according to previously named symbols. No signal has been accepted as an *S* signal if it has not re-appeared at least once in the records. The horizon 3,475 (*S* 3) in No. 34 gives the only exception. As this value is the largest one found so far, it seems appropriate to give, more in detail, the interpretation of this record, and the motives for identifying the signal in question as a sub-bottom reflection: Two clear signals marked $S1_1$ and $S1_2$ may be seen between *P1* and *P2*. They are repeated in due positions after the *P2* signal, and marked $S2_1$ and $S2_2$. The latter is somewhat obscured by the preceding signals. A very distinct signal, marked $S1_3$ follows after P2. The reason for not identifying it as an $S2_3$ signal lies in the fact that in such a case there should have been a corresponding *S1* signal, which is not to be seen in the record. The reason for not identifying it as a *B* signal is that no clear corresponding *B2* signal is found in its appropriate place in the record. The $S2_3$ is obscured by the preceding *P3* signal. This interpretation is substantiated by the observation that the bottom was very smooth, having the *0* degree of ruggedness, as seen in TABLE 4.

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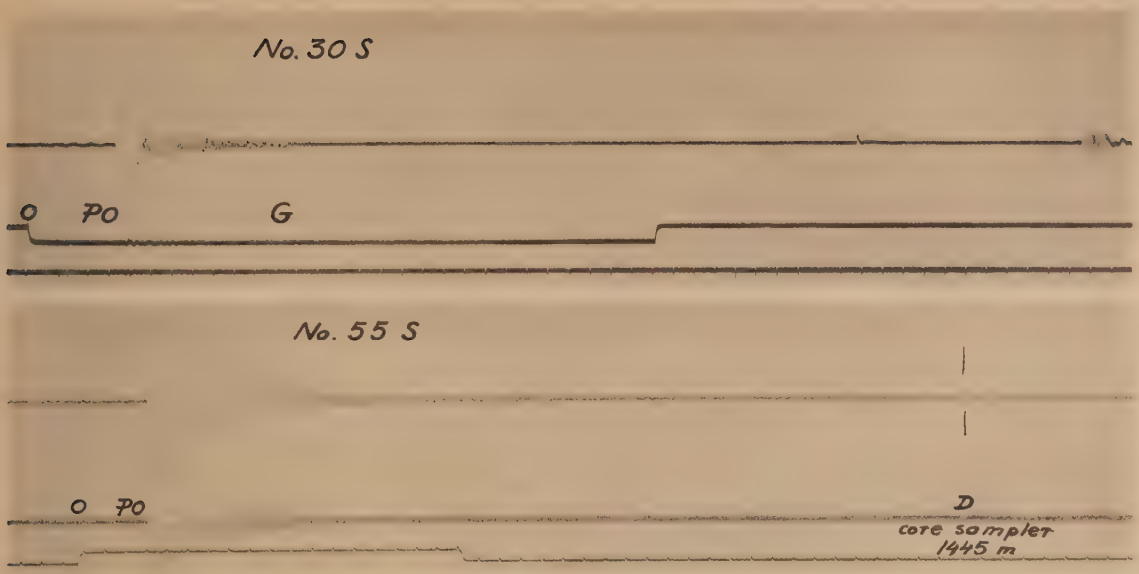
RECORDS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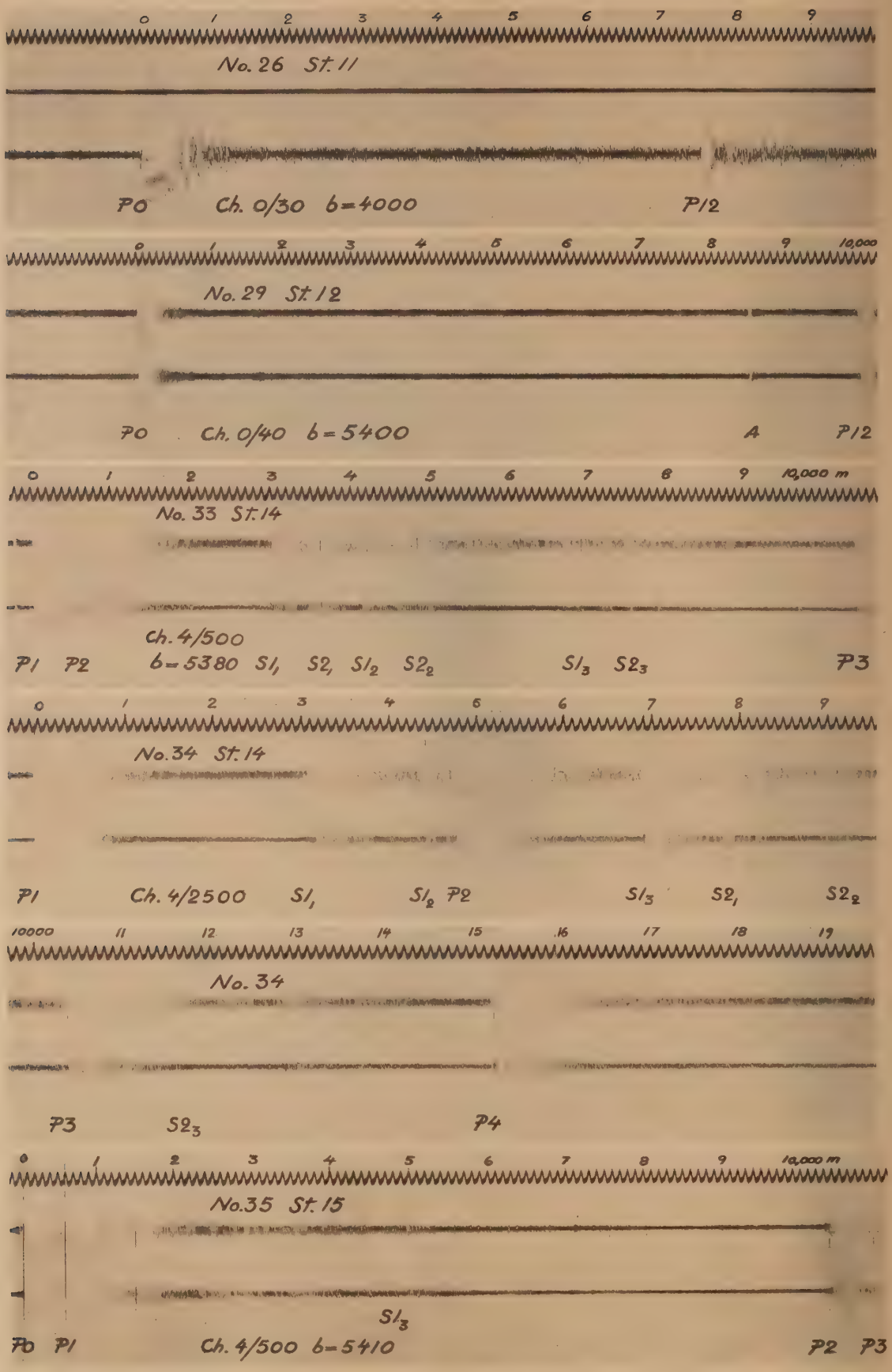
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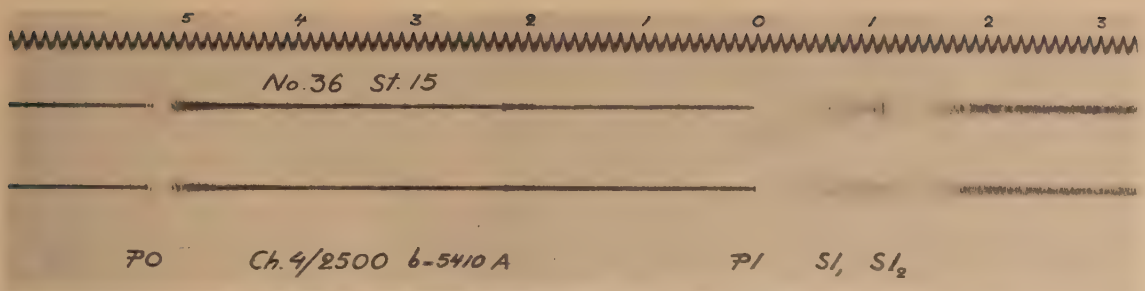
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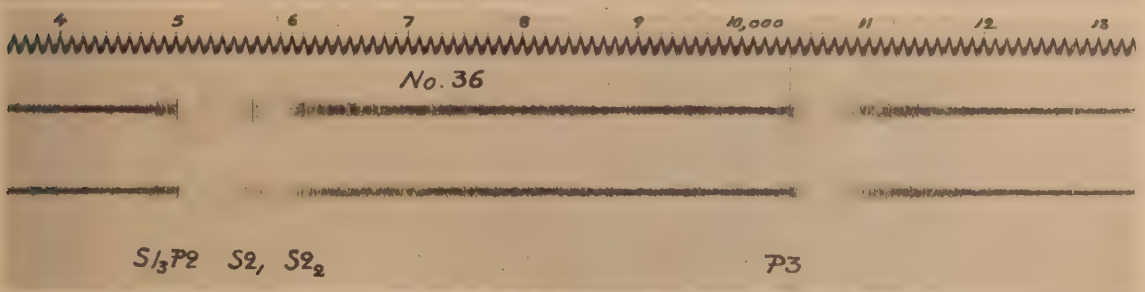
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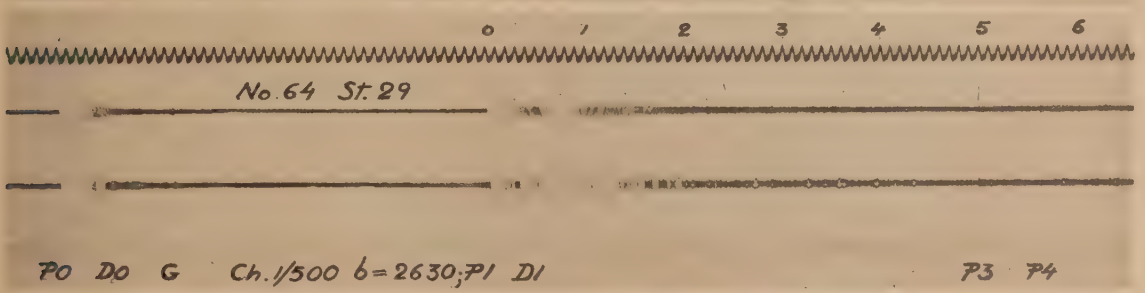
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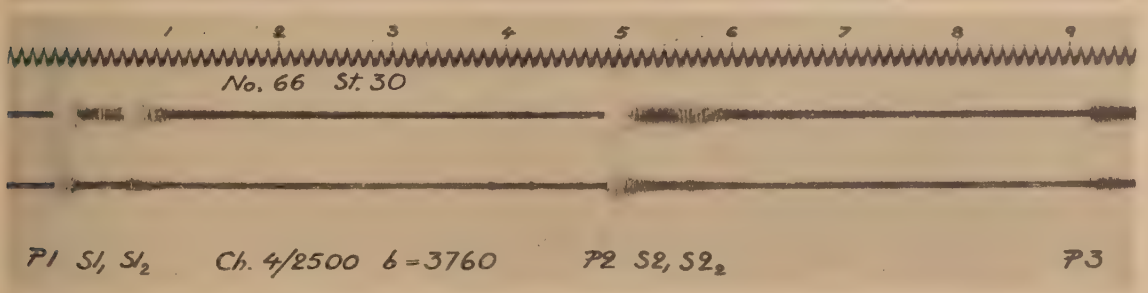
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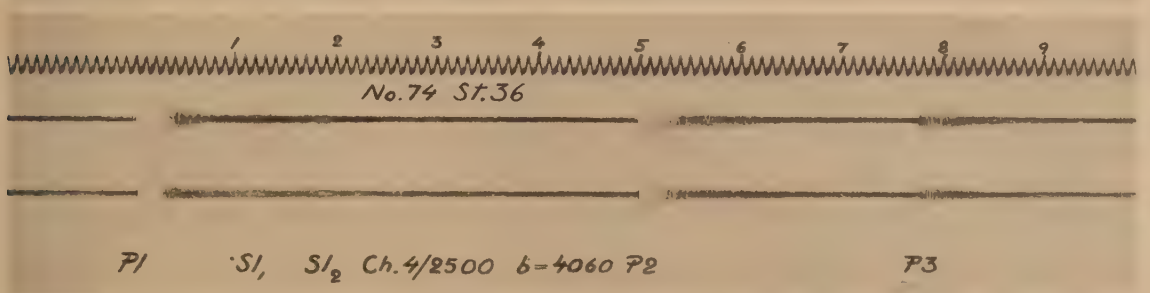
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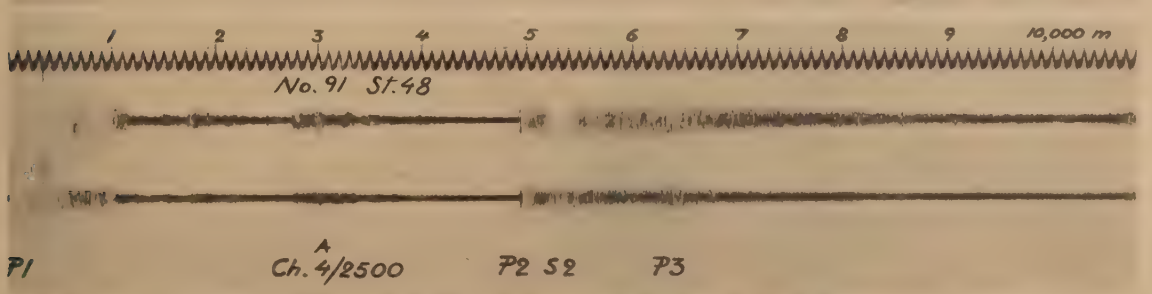
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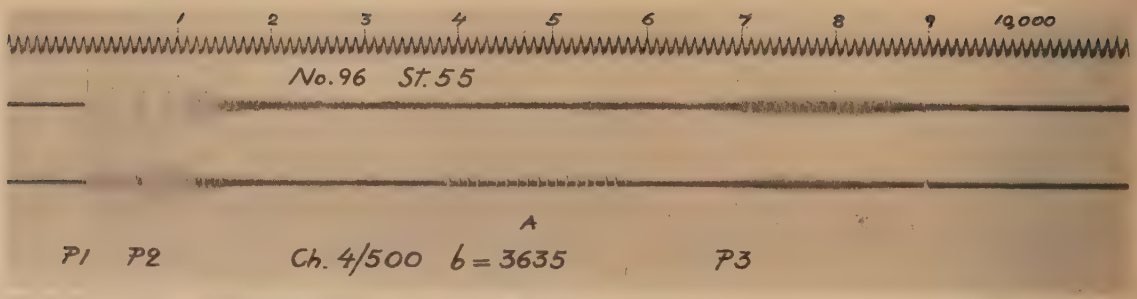
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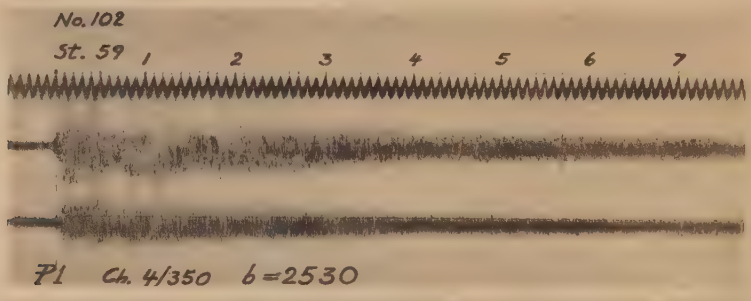
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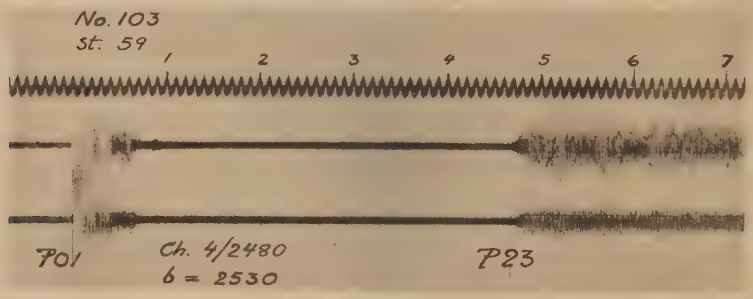
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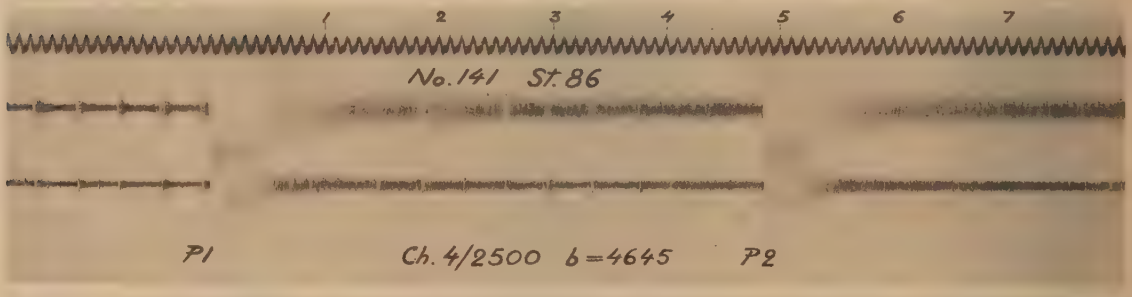
P23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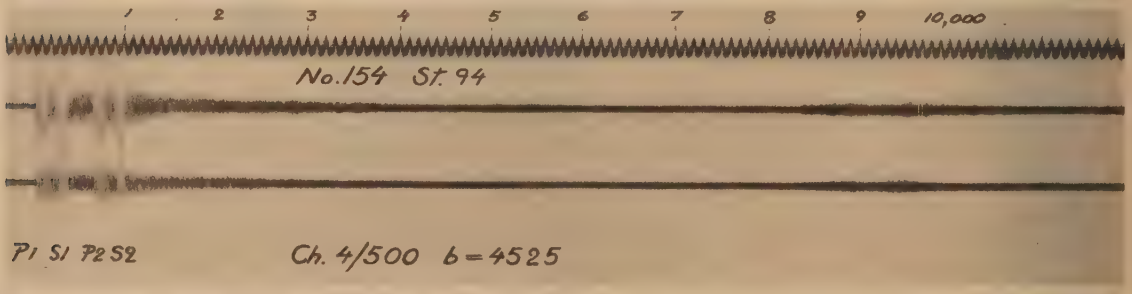
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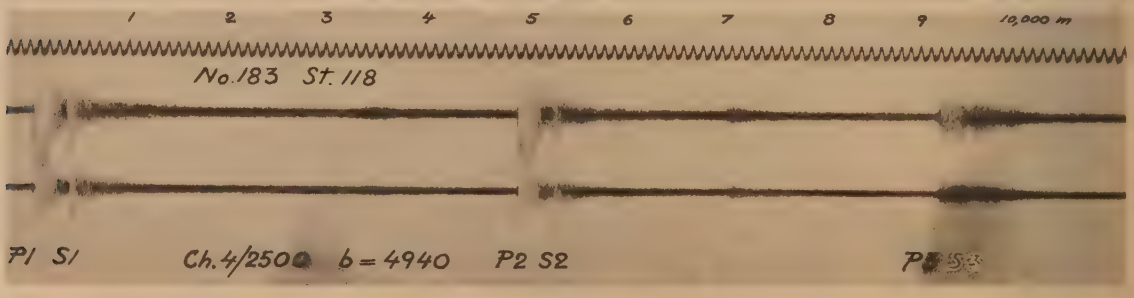
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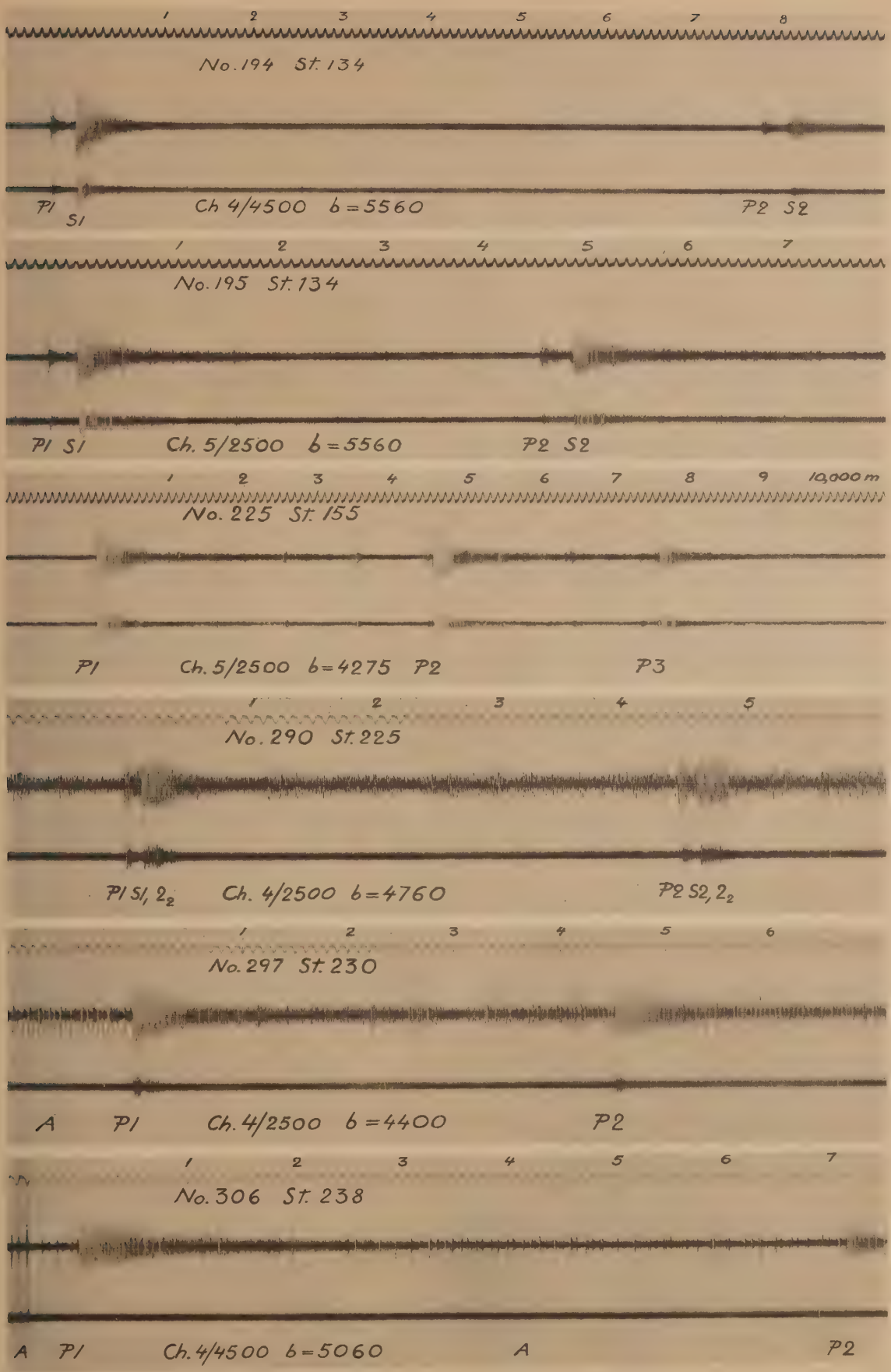
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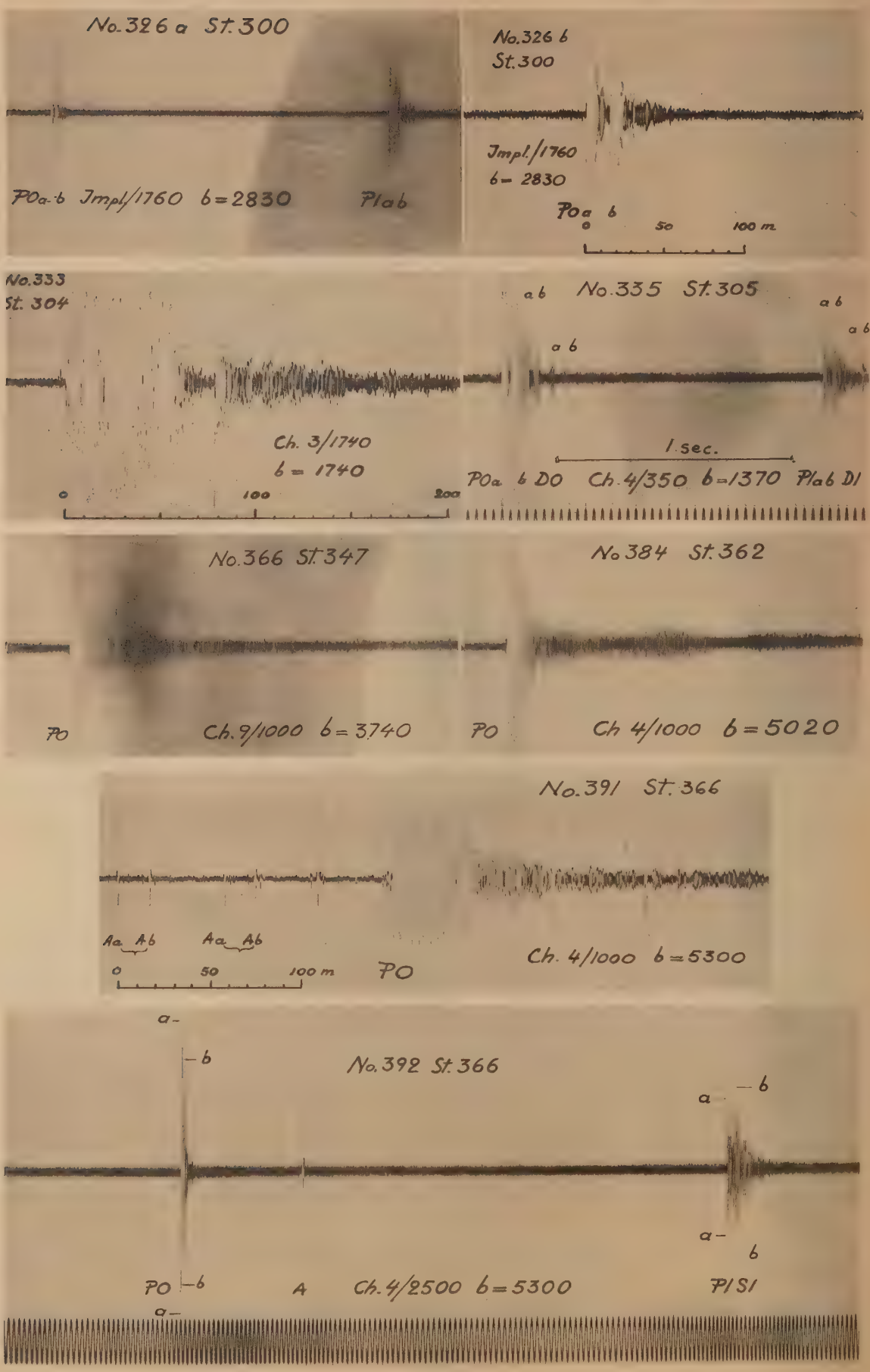
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0 50 100 m
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St. 304
Ch. 3/1740
b = 1740
0 100 200
a b No. 335 St. 305
a b
a b
a b
1 sec.
POa b DO Ch. 4/350 b=1370 Plab DI
No. 366 St. 347
PO Ch. 9/1000 b=3740
No. 384 St. 362
PO Ch 4/1000 b=5020
No. 391 St. 366
Aa Ab Aa Ab
0 50 100 m PO
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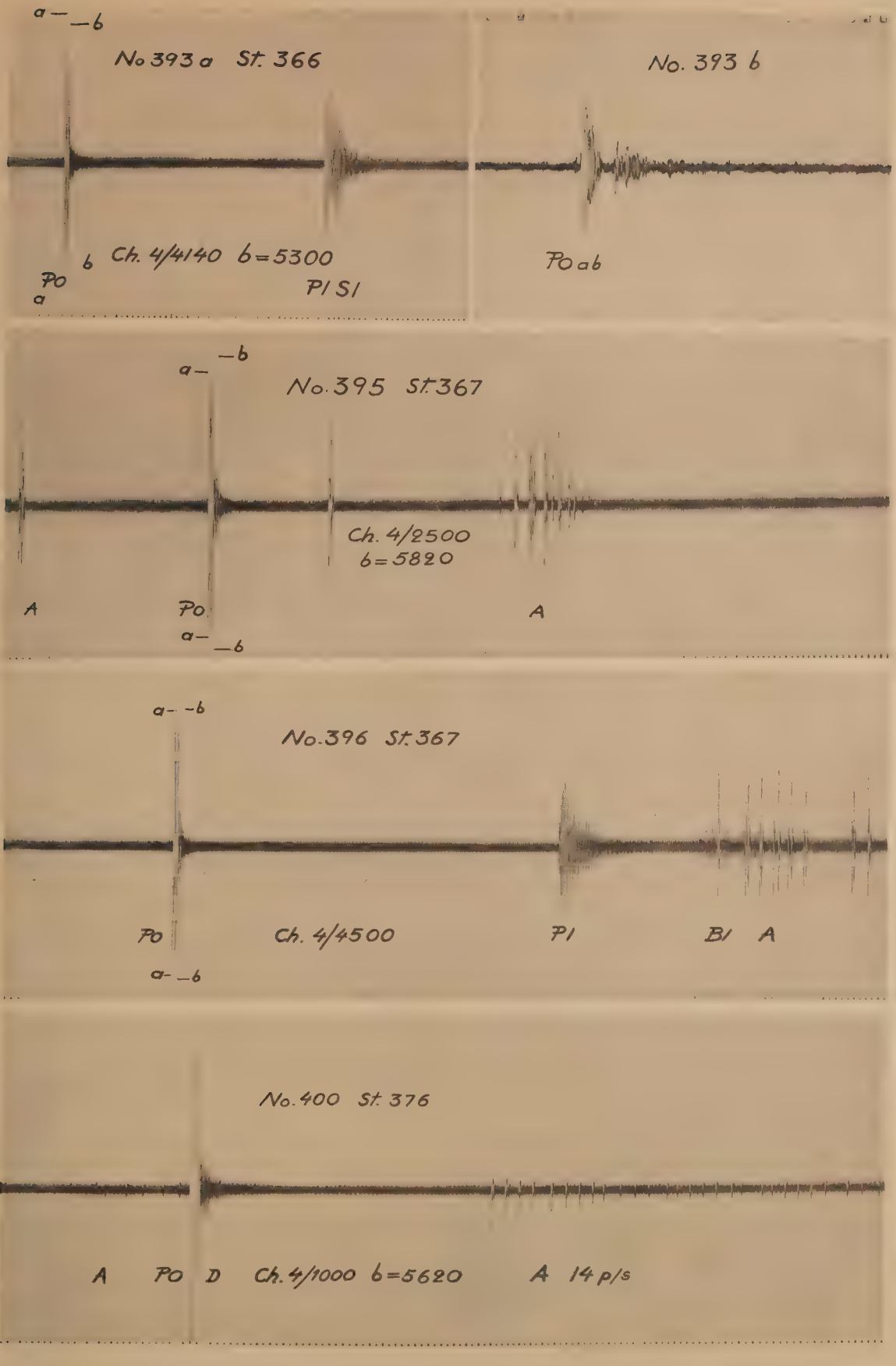
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Po ab
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Ch. 4/2500
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A
Po
A
a— —b
a- -b
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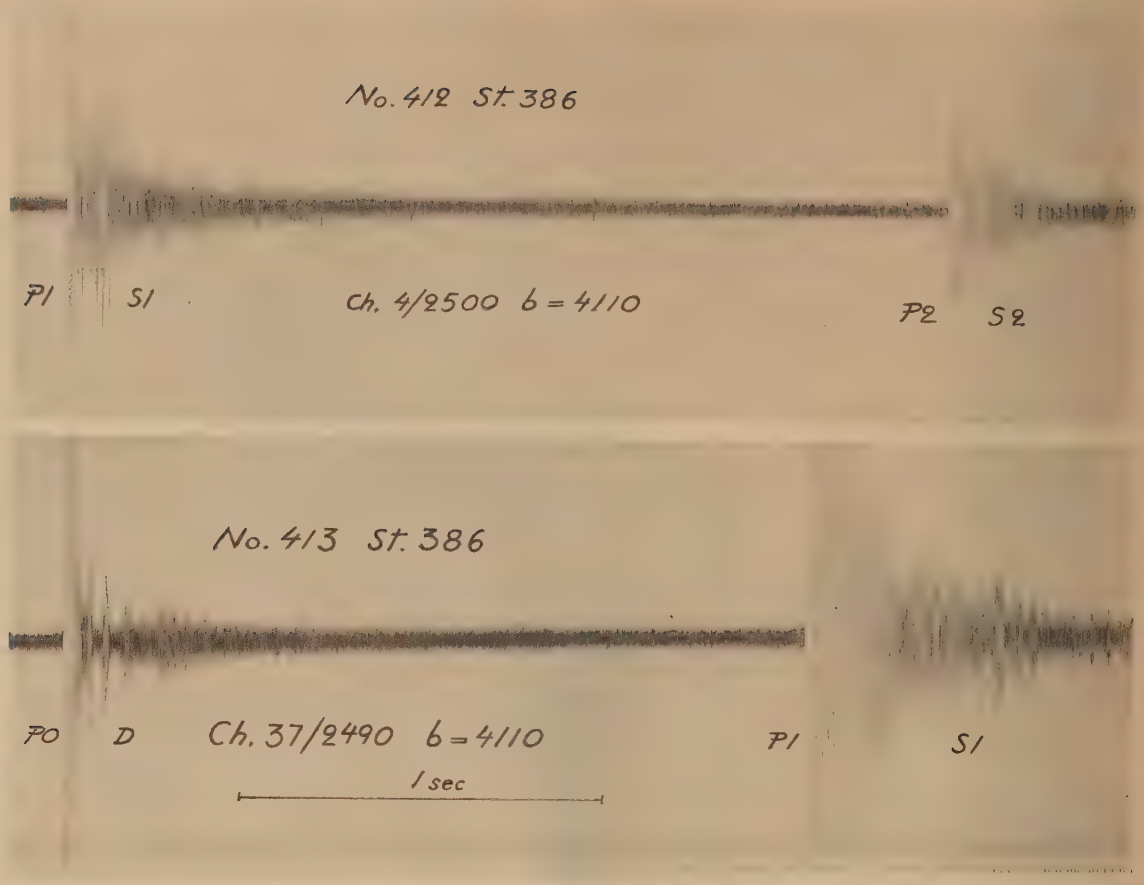
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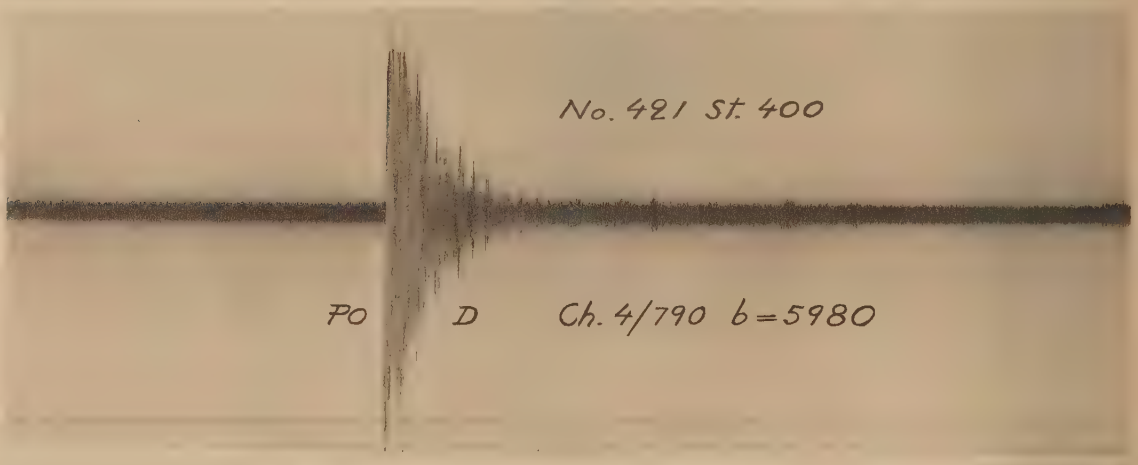
P1
S1
Ch. 4/2500 b = 4110
P2
S2
No. 413 St. 386
PO
D
Ch. 37/2490 b = 4110
1 sec
P1
S1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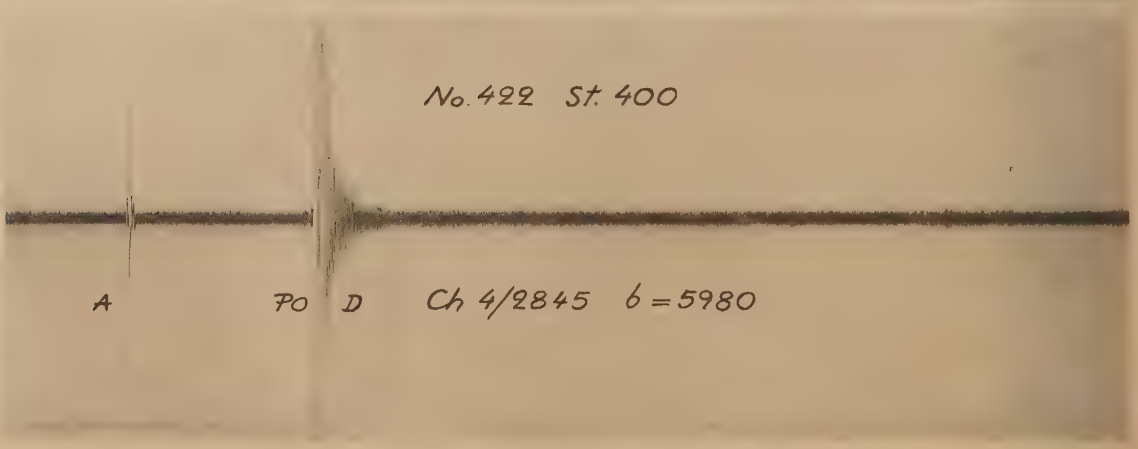
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REPORTS OF THE SWEDISH DEEP-SEA EXPEDITION. VOL. IV
BOTTOM INVESTIGATIONS. NO. 2

DEEP-SEA CORING

BY

BÖRJE KULLENBERG

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Introduction

The main object of the Swedish Deep-Sea Expedition 1947—48 was to investigate the deep-sea deposits by applying a new coring technic making it possible to obtain nearly 20 m long cores from the deep-sea bottom (KULLENBERG 1944, 1947).

Earlier coring technic is too well known to need by treated in detail here. Various modifications of V. W. EKMAN's gravity sampler (EKMAN 1905) were used during oceanographic expeditions up to 1935. As a rule this very excellent apparatus was not able to secure more than 1 m long cores, though EKMAN himself obtained 2 m long cores by using a wider tube than was applied in later modifications. The return to a wide tube effected by PH. H. KUENEN during the Snellius Expedition made it possible to obtain nearly 3 m long cores under favourable conditions (KUE-

NEN 1932). In 1935 the PIGGOT gun brought about a great progress, increasing the core length to 3 m (PIGGOT 1936, 1941). H. PETTERSSON conceived an idea to use the pressure of the water to force a coring tube down into the ocean floor. Though the idea could not be carried into effect, the attempt occasioned a systematic study of the problem, leading ultimately to the new coring technic mentioned above.

Acknowledgements

The author is under great obligation to Professor HANS PETTERSSON, Director of the oceanographic institute in Gothenburg and Leader of the Swedish Deep-Sea Expedition. I have had the great privilege to be working under Dr. PETTERSSON for 25 years, and I have had the benefit of his fertility of imagination, his resourcefulness, and his wide reading. It was Dr. PETTERSSON who suggested, at an early date, that the hydrostatic pressure at the bottom of the sea should be utilized for coring purposes, and the first attempts to carry this into effect were made by Dr. PETTERSSON and me in direct collaboration. By initiating the Swedish Deep-Sea Expedition Dr. PETTERSSON procured the opportunity to employ the new coring technic on a large scale.

I am much indebted to Mr. AXEL JONASSON who constructed the first vacuum corers and piston corers and suggested many important improvements during our numerous discussions, among other things the release mechanism finally chosen. During the Swedish Deep-Sea Expedition Mr. JONASSON was my head assistant. I am also much indebted to Mr. HARRY KVIST, who assisted with the deep-sea coring on board the »Albatross».

I am greatly indebted to my friend Mr. AUGUST NILSSON whose fifty years seamanship made him the right man to organize the operation of the unwieldy gears on board, though high age prevented him from partaking in the Swedish Deep-Sea Expedition.

My sincere thanks are due to the master of M/S »Albatross», Captain NILS KRAFFT, for his great skill and helpfulness during the expedition, and to the officers and cadets for all their assistance. I am especially indebted to the Chief Engineer of the »Albatross», Mr. HUGO ENVALL, who put his technical skill at my disposal on many difficult occasions.

Finally I wish to thank my collegues on board the »Albatross», especially Dr. GUSTAF ARRHENIUS and Mr. RUTGER IRGENS who belonged to the team occupied with deep-sea coring.

The Hydrostatic Pressure as a Means of Collecting Long Bottom Samples

M. KNUDSEN has successfully used the hydrostatic pressure at the bottom of the sea to force a core sampler down into a hard bottom. During the last years of the 19th century C. G. J. PETERSEN started very extensive bottom investigations in Danish waters aiming at a quantitative determination of the amount of fish food present in the upper sediment layers. In the course of the investigations PETERSEN (1918) developed his well known »PETERSEN grab», a most efficient bottom sampler, especially on soft bottoms. In some places, however, the bottom was too hard for the instrument, and in order to facilitate the extension of the investigations to such hard sandy bottoms M. KNUDSEN (1927) developed a new type of bottom sampler for hard bottoms, making the hydrostatic pressure of the water force the bottom sampler down into the bottom.

The apparatus consists of an iron tube, 30 cm high and 36 cm in diameter, open below and closed above. At the top there is a waterpump that can be operated from the ship, the tube standing on the sea bottom in shallow water. Then water is pumped

out of the tube, and the surplus of pressure thus acting downwards on the lid will force the tube into the sea bottom. After being filled with sediment the tube is turned upside down by means of a special device, and can then be hoisted up without losing the sample.

By testing the sampler on sandy bottoms at a depth of 3 m under favourable weather conditions it was possible to keep the instrument under close observation during the procedure. It was then observed that no funnel-shaped depression was formed outside the tube, but that the latter sank slowly down into the sea floor. In most of the samples a natural stratification was found, often with considerable difference between the strata, and the bottom organisms were as a rule discovered in their natural position. Hence it may be assumed that the bottom sampler will normally go right down into the sea floor without drawing up bottom material into the tube from the area outside that covered by the mouth of the tube itself.

The KNUDSEN sampler could only be used in shallow water, because at a great depth it would not be possible to operate the water-pump from the ship. Unaware of KNUDSEN's work H. PETTERSSON had the idea of utilizing the high pressure at great depths to force a coring tube down into the bottom by evacuating the tube before sending it down to the sea floor, the lower end of the tube being closed during the descent by a valve opening automatically when the bottom was reached. In the KNUDSEN sampler only a fraction of the hydrostatic pressure was utilized, the water pressure within the tube being only slightly diminished by the water pump. Owing to the great width (36 cm) of the tube, the resultant force was nevertheless sufficiently great to force the tube down into the sea floor. PETTERSSON, however, aimed at cores several metres long, and so the diameter of the tube had to be considerably smaller than in the KNUDSEN sampler. The hydrostatic pressure at a depth of 4,000 m being 400 kgp/cm^2, the force acting at the top lid of the sampler would, however, be sufficiently great to overcome very great resistance. In collaboration with Dr PETTERSSON the present writer constructed a »Vacuum core sampler» accordin to this principle (PETTERSSON and KULLENBERG 1940, 1941). It consisted of a steel tube with an interior width of 5 cm and a length of 220 cm. At the top it was closed by a removable watertight lid, fitted with a valve for the evacuation of the tube. At the lower end it was closed during descent by means of a piston with leather packings, the piston being kept in position during descent in such a way that it was released by the impact against the sea bottom. During experiments at a depth of 400 m I found, however, that the piston, when released, was hurled into the tube at such a high velocity as almost to knock off the top lid. Further, the tube was instantaneously filled with sediment from the very top layer before it had time to move very far downwards after the impact against the bottom.

The physical properties of the sediment *in situ*, which are not very well known, show a wide range of variation. Some sediments do not resist a change of shape, behaving in this respect very much like a fluid; as an instance may be named an almost liquid *Globigerina mud* found in some cores obtained in the Western Mediterranean in 1946. In such a sediment not even the KNUDSEN corer may have functioned properly. Other sediments make a certain resistance to attempts at changing their shape, the shearing strength being quite considerable. As to the resistance to tearing the present writer has met with a sediment in the Skagerrak; a rather fine-grained blue mud with about 14 per cent lime, the tensile strength of which exceeded 10^5 dynes/cm^2. Such a sediment is favourable to the proper functioning of the KNUDSEN corer as, obviously, the pressure difference

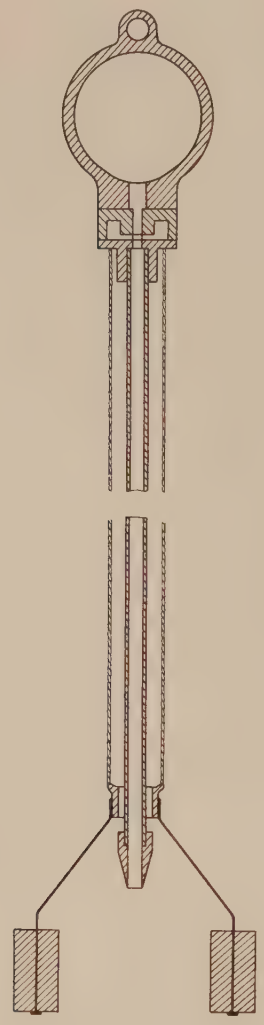

Fig. 1. Schematic drawing of the vacuum corer.

between the water outside and inside the coring tube can be higher, without damaging the sample, the greater the shearing strength and the tensile strength of the sediment are. A shearing strength able to resist a pressure difference amounting to hundreds of atmospheres, as required in the case of the vacuum corer suggested by PETTERSSON, is not likely to be found in any recent sediment, however, and so the method had to be abandoned.

During the experiments with the vacuum core sampler suggested by PETTERSSON the present writer arrived at the conclusion that the main difficulty when trying to obtain long cores was not so much caused by the necessity to force a long tube into the sediment, which turned out to be a mere question of increasing the weight of the corer very considerably, as far more by the necessity to force the sediment to enter the tube, and to do so with the smallest possible dislocations of subsequent layers. *I therefore suggested that the hydrostatic pressure at the sea floor should be used exclusively to force the sediment to enter into the tube, the action being regulated by means of an adequate valve so as not to disturb the stratification.*

This was brought about in the following way (PETTERSSON and KULLENBERG 1940, 1941). The coring tube, which was not to be evacuated as in the original vacuum corer, was attached to a strong cylindrical or spherical container at its top end. The communication between the tube and the container was closed by a small steel cylinder fitting very accurately in a boring, the diameter of which was 30 mm in a corer intended for moderate depths and 15 mm in another corer, intended for great depths. Before the corer was sent down some water was poured into the container so as to make the remaining vacant space equal to the volume of the tube, and then the container was evacuated. The cylinder was kept in position by three steel pegs, both ends of which were cut obliquely so as to fit, one end in a corresponding groove in the cylinder, and the other end into a conical steel ring keeping the pegs in position. The air pressure, and later the water pressure, acting on the cylinder pressed the pegs radially outwards, and the pegs acted on the conical ring upwards. The ring, however, was kept in position by an iron weight suspended in the ring and hanging about ½ m below the lower end of the coring tube, acting as a pilot weight.

As soon as the pilot weight arrived at the bottom the cylinder was released and was hurled into the evacuated container by the pressure of the water filling the tube, and

then the water spurted from the tube into the container. However, the entrance of the water into the vacuum container was obstructed by a circular metal plate at the top of the tube with only a small opening in it. The depth being known, it is possible to calculate the rate at which the water will stream into the container. The sediment, unable to resist the great hydrostatic pressure, must enter the collecting tube at the same rate. If the corer is being lowered at a corresponding velocity, it will go down into the sediment with the same velocity at which the sediment is being forced into the tube, and then the sample will not be distorted. The throttle-valve at the top of the tube being interchangeable, it is possible to obtain a suitable lowering velocity at any depth.

If lowered uniformly the core sampler will keep a constant velocity until the resistance caused by the sediment is equal to the weight (in water) of the corer. Then the velocity will decrease rapidly, and the corer will very soon come to a standstill, the kinetic energy being small. Therefore, the deepest portion of the core will be more or less distorted. I have tried to meet this difficulty by introducing a second throttle-valve about 1 m above the lower end of the tube, consisting of a piston with a very small weight moving in the tube with a very small resistance and fitted with a similar opening as the throttle-valve at the top of the tube, though a smaller one, adequately dimensioned. As, during the descent of the corer into the bottom, the water in the tube was streaming upwards (in relation to the tube) at a comparatively high velocity, the piston referred to will move with the water, though at a slightly lower velocity. A certain amount of water passed through the small opening in the piston, and a corresponding pressure difference was created between both sides of the piston, barely great enough to move the piston. As the piston arrives at the top of the tube it will stop there, and during the remaining descent of the corer the water will leave the tube more slowly corresponding to the smaller entrance now available.

Fig. 2. The vacuum corer ready to be lowered.

At moderate depths the friction between the sediment and the inner walls of the tube will cause some trouble. As the core length increases, the friction will diminish the pressure of the water inside the tube, and accordingly the water will flow more and more slowly into the vacuum container, thus making the sediment to enter the tube at a rate that would cause dislocations. At a great depth the relative change of the pressure will be too small to cause any inconvenience. Even at a moderate depth the difficulty can be eliminated by allowing the corer to fall freely to the bottom, thus obtaining a very high velocity. Then apparently the sediment will resist any change of its shape very strongly, and the elastic forces thus developed by the

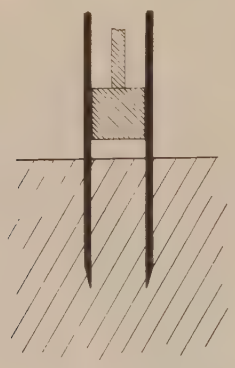

Fig. 3. Principle of the piston corer.

sediment will modify the pressure in the tube sufficiently to allow the sediment to enter the tube undistorted. By proceeding in this manner I have obtained cores in a river mouth in the Baltic, where thousands of very thin annual varves could be found, many of which contained fossil insects in such a completely undisturbed condition as to prove definitively the absence of any distortion of the sediment. This is a rather complicated procedure, however, as it necessitates the use of a double set of pilot weights.

It is obvious that the vacuum core sampler has serious shortcomings, the principle one being the difficulty to make the corer move at the velocity necessary to obtain undistorted cores. In fact, the water running from the coring tube to the vacuum container has to pass not only the throttle valve, but also the boring belonging to the release mechanism. To compute the unreeling speed correctly one has to consider the total resistance to the water flowing from the coring tube to the vacuum container, and as the release mechanism, as described above, does not completely prevent water from the outside to enter the container by the boring it is difficult to compute the effective resistance to the water coming from the coring tube. Accordingly, one can hardly expect to compute correctly the unreeling speed necessary to obtain an undisturbed core at a great depth. It must be remembered that the distortion caused by an erroneous unreeling speed will be proportionate to the error. Further, at a great depth it is not possible to keep the velocity of the corer constant during the critical period when the corer is going down into the sediment. With a 15 m long coring tube the length of this period will be 10—20 seconds or even more. During this period the tension in the cable will continually decrease by the weight of the corer, say 1,200 kg. Taking the depth to be 6,000 m and the medium diameter of the cable to be 14 mm, this decrease of the tension will cause the cable to contract by about 7 m. The critical period just referred to is long enough to allow the cable to adapt its length to the changed tension. Accordingly, the velocity of the corer will be smaller than the unreeling speed as the corer is going down into the sediment, and, owing to the inertia of the corer, the drag of the cable, and, possibly, the non-constancy of the resistance of the sediment, the velocity will not remain constant. It is of course possible to adapt the throttle valve to an adequate medium velocity, smaller than the unreeling speed, but it is not possible to do so very accurately, among other things because the resistance raised to the corer by the sediment is insufficiently known. Therefore, though it may be possible to obtain long cores at very great depths by a vacuum core sampler, the cores will necessarily be distorted, and possibly very much so. These, and other considerations convinced me that the vacuum core sampler could not be relied upon in such a great enterprise as the Swedish Deep-Sea Expedition, and therefore, it was considered necessary to develop another core sampler better suited to the purpose.

The Piston Core Sampler

The piston core sampler (Kullenberg 1944, 1945, 1947) is based on a method to procure samples for ground investigations, developed by C. Caldenius and J. Olsson (1925) of the

Geotechnical Department of the Swedish State Railways.

The method should be clear from Fig. 3, which shows a tube going down into the sea bottom. Inside the tube there is a closely fitting piston, which is being kept immobilized immediately above the bottom. As the tube is going down, the friction between the sediment and the inner wall of the tube will exercise a downward pull on the core, which is opposed, however, by the hydrostatic pressure on the bottom. The hydrostatic pressure will not allow a vacuum to be created between the piston and the top of the core as long as the frictional forces do not exceed the hydrostatic pressure. This will never be the case in deep sea, but it may happen in shallow water. However, when the tube is penetrating the bottom, the friction will cause the pressure immediately below the piston to be diminished as compared with the hydrostatic pressure. The pressure difference between the lower end of the tube and the top of the core will automatically balance the frictional resistance to the core, which, therefore, will be a correct representation of the sediment column *in situ*, provided the piston does not move, which condition it is possible to fulfil very nearly.

In the piston corer the »piston principle» has been combined with the »free-fall principle», introduced by the present writer in 1944 (KULLENBERG 1944) and independently developed by M. J. HVORSLEV and H. C. STETSON (1946). For the sake of perspicuity a brief description of the corer is given here. A steel tube, the maximal length of which so far has been about 20 m, is loaded with heavy weights corresponding to the length of the tube and the properties of the sediment. The tube is suspended from the release mechanism, the most prominent part of which is a lever, one arm of which is about 15 times as long as the other one. The tube is suspended from the short arm and is balanced by a counter-weight suspended from the long arm, the counter-

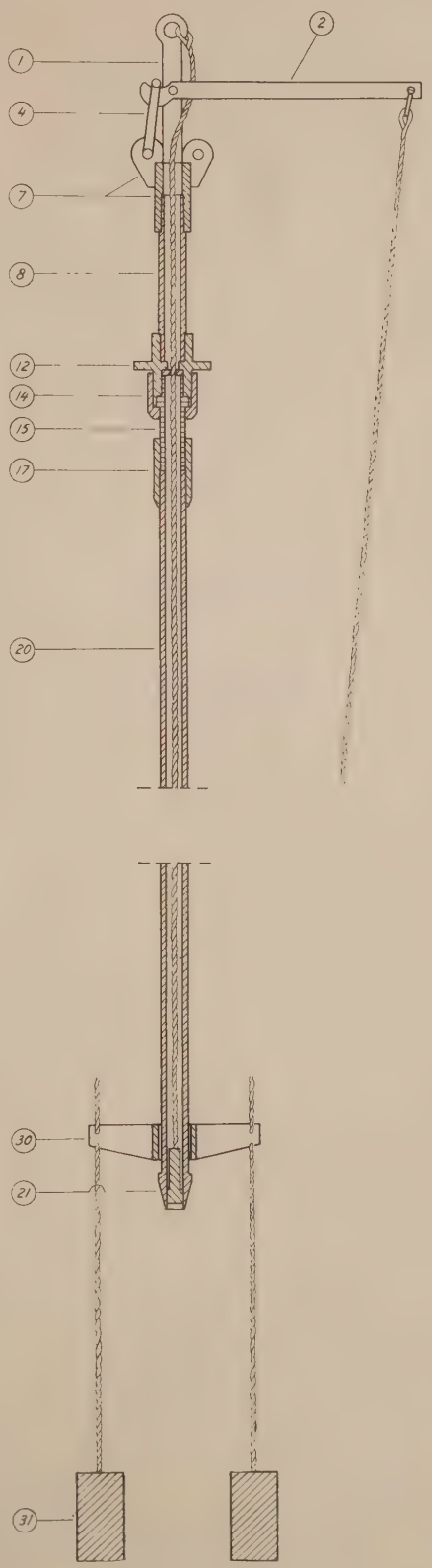

Fig. 4. Schematic drawing of the piston corer.

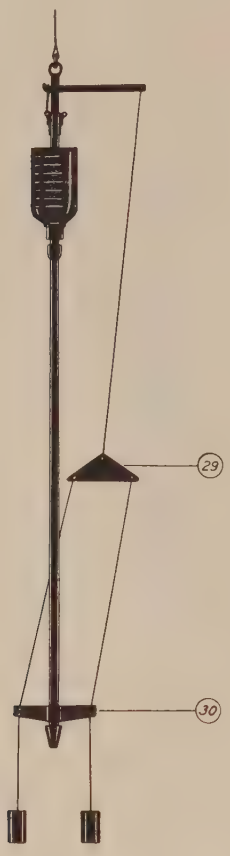

Fig. 5. The piston corer during the lowering.

weight being about one tenth of the weight of the rest of the core sampler. The tube is suspended so that it will slip off the release mechanism if the counter-weight is put out of action. The release mechanism is furnished with an eye for the steel cable that serves to lower the core sampler to the sea floor. The counter-weight is suspended from a rope so as to hang at least one metre below the lower end of the tube. It is attached to the tube in such a manner as to permit it to move up and down the latter.

The steel tube contains a brass lining. In the lower end of the tube there is a piston, which fits closely inside the brass tube and is able to move in this. The piston is connected with the release mechanism by a steel rope that runs up through the tube.

When the core sampler is approaching the bottom the counter-weight will act as a pilot weight, striking the bottom first and unloiadng the lever of the release mechanism in doing so. Then the tube will slip off and drop into the sediment at a rather high velocity. The diminished tension of the cable is read off on board the ship by a dynamometer, where upon the winch is stopped, so that the piston is arrested. Obviously the sediment is forced to enter the tube, as otherwise a vacuum would be created in the tube below the piston, and no matter how deep the tube penetrates the bottom the length of the core will be equal to the penetration depth, provided the water is not to shallow.

We shall now give a detailed description of the piston corer.

COMPONENT PARTS OF THE PISTON CORER

Item	Fig.	Name of detail
1	4, 6, 7	Stand for the lever
2	4, 6	Lever
3	6	Bolt for the lever
4	4, 8 a	Suspending link
5	—	Bolt for suspending link
6	8 b	Safety link
7	4, 6	Top cylinder
8	4, 9	Tube supporting drive weights
9	9	Clamp securing drive weights
10	9, 10	Semicircular drive weights
11	9	Drive weights shaped as truncated cones
12	4, 9, 11	Cylinder supporting drive weights
13	13	Brass ring securing top of lining } »The coupling»
14	13	Big nut with interior rim } »The coupling»
15	13	Tubing with outside rim } »The coupling»
16	12	Steel plate serving as piston catch
17	14	Screw coupling at top of coring tube
18	15	Screw coupling joining sections of coring tube
19	16	Screw coupling at lower end of coring tube
20	4, 15	Section of coring tube
21	4, 17	Cutting nose
22	17	Core catcher
23	19	Detail of piston fused to piston rope
24	19	Detail of piston carrying packings
25	19	Nut securing packings on the piston
26	18	Section of lining
27	18	Collar joining sections of the lining
28	18	Frame securing lower end of the lining
29	5	Iron plate triangle supporting item 30
30	4, 5	Bar carrying the pilot weights
31	4, 5	Pilot weights

Fig. 6. The release mechanism.

The release mechanism (Fig. 6) consists of a stand for the lever and the lever. The lever-stand (Fig. 7) is made up of a short steel rod at the bottom and two wrought iron bars welded to the rod. At the upper end the bars are welded to a wrought iron ring to which the long sounding cable is attached when the corer is to be lowered to the bottom of the sea. Halfway between the ring and the rod, both bars have a bore-hole for the bolt serving as an arbor for the lever. The rod fits into the smooth bore of a cylinder (item 7) which is screwed to the top of the tube in order to fix the release mechanism in its proper position. The rod has two slits opposite to each other, and the slits are extended in the bars half-way to the lever. The object of the slits is to let out the rope that joins the piston to the release mechanism, the rope being fastened directly to the eye of the core sampler. The lever (item 2) is a wrought iron bar, 2 cm thick, 5 cm wide, and 85 cm long. It has a bore for the axis a few cm from one end, and another one near the other end, serving to suspend the counter-weight. The bulk of the core sampler is hung on the short arm in a link (item 4) fastened to the cylinder (item 7) just referred to. The arm is 5 cm long, and is shaped like a beak so as to make it easy for the suspending link to slip off as soon as the arm has been sufficiently lowered. The other arm, which is depressed by the counter-weight, is 70 cm long.

The weight-stand (Fig. 9) is a steel tube (item 8) with a steel cylinder screwed to each end of it. The diameter and the wall thickness of the tube are the same as those of the coring tube. It has male screw-threads at both ends.

The cylinder at the top end (item 7) has an axial bore 75 mm in diameter. At the lower part it has female screw-threads, serving to fasten it to the weight tube, whereas the bore is smooth in the upper part, into which the lever-stand (item 1) is inserted. At the top the cylinder is fitted with two loops opposite to each other. In one of the loops there is fastened the link (item 4) just referred to, serving to suspend the bulk of the core sampler from the short arm of the lever. The link is able to

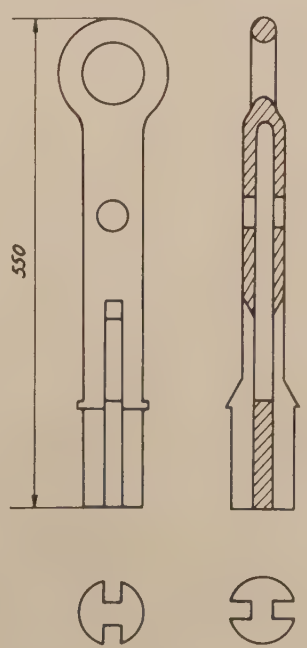

Fig. 7. The lever-stand.

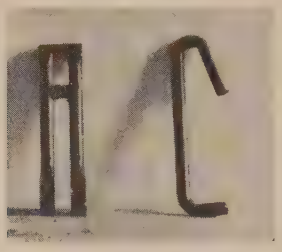

Fig. 8. Suspending link and safety link.

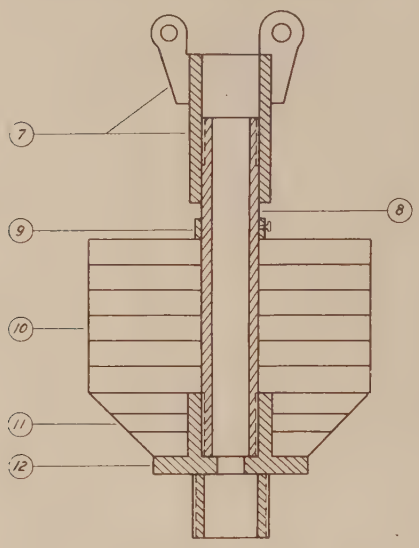

Fig. 9. The top of the piston corer.

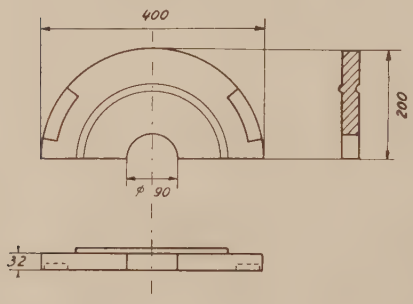

Fig. 10. A semi-circular drive weight.

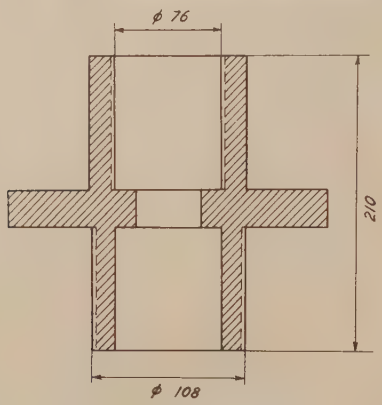

Fig. 11. Cylinder supporting the drive weights.

turn round the bolt at its lower end (item 5), which is run through the loop. In the other loop there is fastened a safety link (item 6), serving to fix the lever in a position perpendicular to the tube during the operations necessary to put the core sampler into the sea.

This will prevent the tube from being accidentally released. The safety catch is not removed until immediately before the lowering of the core sampler is started when all preparations are completed and the corer is hanging in the water in a vertical position.

The steel cylinder at the lower end of the weight tube (item 12) has a thick shelf running round it externally to support the weights necessary to force the corer down into the bottom. The rest of the cylinder has an outside diameter of 110 mm with a bore of 75 mm, which, halfway, is narrowed to a diameter of 30 mm, the interior rim thus obtained serving as a piston catch to stop the piston when the corer has gone down into the sediment to its full length. Above the external shelf the cylinder has female screw-threads serving to fasten it to the weight tube, and below the shelf it has male screw-threads.

The drive-weights (Figg. 9 and 10) are supported by the weight-tube and the cylinder at its lower end. The lowest drive-weights are truncated cones (item 11) with a central bore for the tube. The other drive-weights are semicircular plates of iron or lead (item 10) with a notch for the tube, each weighing 20 kg. Underneath, the iron plates are provided with holes for the pegs in the top of the subjacent plates. They are laid cross-wise over each other, two in each layer, being thus mutually fixed in position by the pegs. With the lead plates the holes are changed into semi-circular grooves, and the pegs into semicircular ridges fitting into the grooves of the subjacent plates. Above the uppermost weights a steel clamp (item 9) is attached to the tube by screws, serving to prevent the drive-weights from jumping off at occasional jerks, or when,

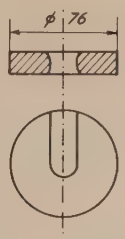

Fig. 12. Piston catch.

occasionally, the corer is toppling over at the bottom of the sea.

The coupling (Fig. 13) serves to facilitate the removing of the upper part of the corer from the collecting tube, which operation has to be performed every time the corer has been used. The coupling is made up of three pieces. One of them (item 15), made of steel, has an axial hole with a diameter of 50 mm, except at the ends, which are wider and are provided with female screw-threads. At the lower end the bore has a diameter of 75 mm, and the screw-threads at this end are intended to fasten the coupling to the top of the coring tube. At the top end the bore has a diameter of 63 mm. The second piece of the coupling (item 13) is fastened here. It is a brass ring with male screw-threads, the outside diameter being 63 mm, and the inside diameter being equal to that of the lining tube, *i. e.* 46.0 mm. The

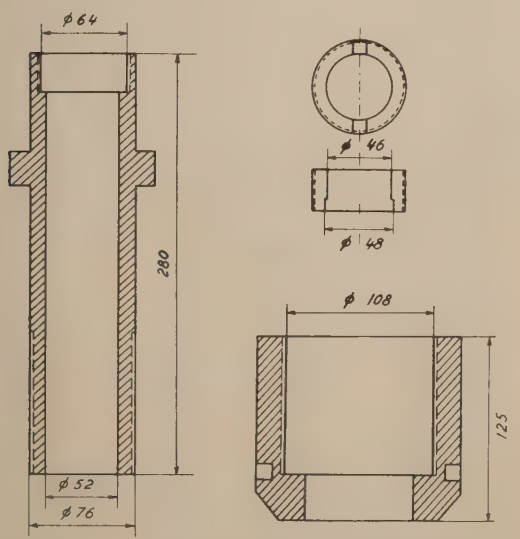

Fig. 13. Component parts of the coupling.

object of the brass ring is to support the top end of the lining tube, so the internal diameter at its lower end is equal to the external diameter of the lining. The third piece of the coupling (item 14) is a big nut with an inside rim at its lower end. There is an outside rim near the top end of item 15, and the nut (item 14) can only be moved until the two rims come together. The nut has an inside diameter of 110 mm, and it has female screw-threads intended to fasten the coupling to the upper part of the corer, corresponding to the male screw-threads at the lower end of

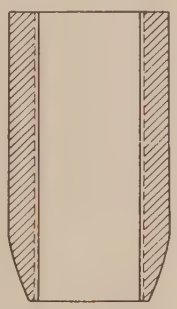

Fig. 14. Screw coupling at the top of the coring tube.

item 12. As the nut can be turned without moving the rest of the coupling, only this detail has to be turned when the coring tube is to be fastened to, or unfastened from, the upper part of the core sampler. The piston catch (Fig. 12, item 16) consisting of a circular steel plate with a cutting-out for the piston rope, is situated at the top of the coupling, inside item 12, below its interior rim.

The coring tube (Fig. 15) is made from cold drawn steel with an internal diameter of 52 mm and a wall thickness of 14 mm. The steel has a breaking strength of about 75 kg/mm², and the percentage of carbon is 0.65 %, of silicum 0.25 %, and of manganese 0.75 %. These cold drawn steel tubes were made by the Sandvik Steel Works Co., Ltd., Sandviken, Sweden.

The tube may be given a length of about 20 m, but it is not always convenient with such

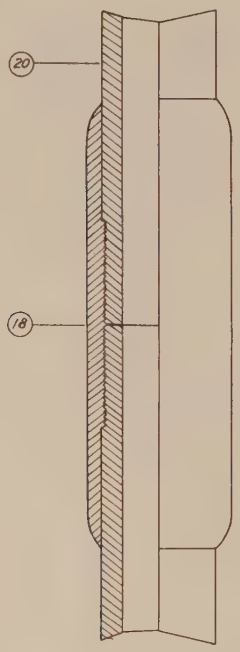

Fig. 15. Coring tube, and screw coupling joining sections of coring tube.

a great length. Sometimes it is not possible to make the tube penetrate to its total length, and in such case it is advisable to adjust the length of the coring tube according to the core length obtainable. There are several reasons for not having the corer longer than necessary. One reason is that the core is apt to be damaged very seriously by the suction produced by the piston during the first stage of the heaving, when the piston is moved from its position immediately above the top of the core to the top of the tube. Then the core will easily break at one or several places, and water will leak in between the displaced core sections. This damage does not occur if the length of the tube slightly exceeds the penetration depth. Another reason is that there is a very considerable risk of breaking or bending the tube when using a 20 m corer, whereas the risk is small when using a 15 m corer and none at all when working with a 10 m corer. Therefore, a 20 m corer should never be used unless the corer can be forced nearly 20 m down into the bottom.

The tube is made up of sections of about 5 m (item 20), which are joined by means of a screw coupling. The screw coupling having a length of 33 cm and a wall thickness of 15 mm, and the exterior screw threading at the ends of the tube sections but slightly diminishing the diameter of the tube, the joints will be quite as strong as the rest of the tube. Prior to the Swedish Deep-Sea Expedition the tube sections were screwed together, the end of one section having internal screw threading and the end of the other section having external screw threading. Then the joints were weaker than the rest of the tube, and it sometimes happened that the corer broke at a joint. Though the screw couplings increase the diameter of the corer from 80 mm to 114 mm at each joint, they do not make it more difficult for the corer to penetrate into the sediment, because some water will fill the wake in the sediment produced by each screw coupling, so that the frictional resistance to the corer between the screw couplings will be diminished, and thus the increased resistance at the joints will be compensated.

The nozzle (Fig. 17) has a maximum external diameter 20 mm larger than that of the coring tube. It is jointed to the tube by means of a screw coupling similar to those connecting the tube sections, though shorter than these. This arrangement has the advantage that the mouth-piece can be connected to any tube section, so it is not necessary to provide the lowest core section with a special screw threading, which obviously makes it easier

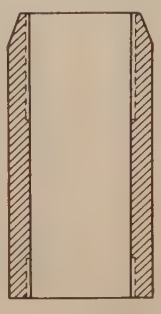

Fig. 16. Screw coupling at the lower end of the coring tube.

to change the length of the corer. The large diameter of the mouth-piece and its screw coupling is a very great advantage, because the friction on the outside walls of the tube when the corer is going down into the sediment will be diminished by the water descending in the wake of the mouth-piece, and hence the force necessary for pulling the sampler out of the bottom will be considerably reduced. During the Snellius expedition KUENEN (1932, 1938) found that to be the case with a 4 m long tube, but during coring operations in the Mediterranean in 1946 I was not able to decide whether it is the case with a longer tube. During the Swedish Deep-Sea Expedition, however, it was proved beyond doubt that in most oceanic sediments it is much easier to pull the corer out of the bottom, when it is provided with a wide mouth-piece. On some occasions the mouth-piece had the same width as the coring tube, and then no screw coupling was used, but the mouth-piece was screwed directly on to the tube, which was provided with internal screw threading, and the tube sections were screwed together, each section having external screw threads at one end and internal screw threads at the other. Then the force necessary to pull a 15 m corer out of the bottom was always very great, amounting to several thousands of kp, and on one occasion the resistance was so great that the cable, which had a breaking strength of 8,900 kp, broke after very violent pulling. When using a wide mouth-piece I rarely found the resistance to exceed 1,000 kp.

The internal diameter of the lowest part of the mouth-piece has sometimes been kept about 1 mm smaller than that of the lining tubes. This was to diminish the friction between the sediment and the inner walls of the tube, which is apt to distort the sediment layers. It is doubtful, however, whether the core is not more damaged by having a smaller diameter than the lining tube than by the friction, and I have found it advisable to

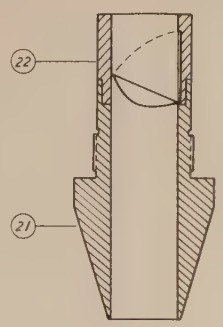

Fig. 17. The mouth-piece.

change the inner diameter of the mouth-piece, making it equal to that of the lining even at its lower end. The mouth-piece is lined with a brass tube that fits so tightly as to adhere to the inner walls.

In the upper part of the mouth-piece there is a core catcher. It consists of a metal sheet so shaped as to form a part of a cylindrical surface, the diameter of which is equal to that of the lining tube, and it is able to close the mouth-piece completely. When open, the core retainer forms a part of the brass lining inserted into the mouth-piece. It is free to turn 60° round a horizontal axis at its lower end, the axis being tangential to the tubing. During the descent of the corer the core retainer is kept in position to the wall of the tubing by the piston. When the corer is going down into the sediment, the core, entering at a very high speed, will keep the core retainer in the same position. When the corer has stopped, and when it is being hauled up to the ship, the retainer will be pressed one or two millimetres into the core by a weak spring, and if the core does not move, nothing more will happen, which is generally the case. If the core starts to slip out of the tube, however, the core itself will force the retainer to close the mouth-piece, and then only the small part of the core below the retainer will be lost.

It must be emphasized that the spring just referred to has to be very weak or the core

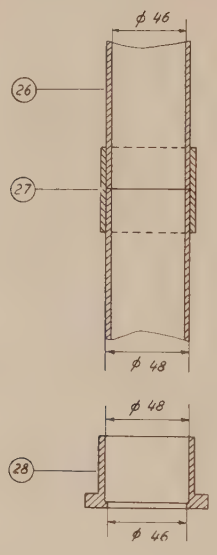

Fig. 18. Lining with a collar, and frame for its lower end.

retainer may cause damage to the core as the sediment enters the tube.

The lining tube (Fig. 18) is made up of brass or stainless steel tubes 70 cm long with 46 mm internal diameter and 1 mm thick (item 26). As the total length of the lining has to be adapted to the length of the coring tube it may be necessary to shorten one lining section, preferably the top one. It is convenient to have the lining tube made up of short sections as it would otherwise be difficult to extract the sample. At the upper end the lining tube is supported by the coupling, and at the lower end it is kept in position by a frame (item 28) as shown in Fig. 18. The mouth-piece is screwed until it is stopped by the frame, whereupon every lining tube piece rests against the adjoining pieces. Thus, the coupling and the mouth-piece will keep the lining tube pieces together longitudinally, and furthermore the adjoining tubes are kept together by short collars (item 27) as shown in Fig. 18. The space between the collars and the coring tube being very small, the lining tube is well supported. The lining tubes should be carefully selected, as the diameter must be the same one everywhere. There must be no appreciable oval deviation from the circular form or the piston may collide with some projecting part of a tube joint and utterly ruin every lining tube in its way.

The lining will be exposed to a certain amount of pressure when the corer is going down into the sediment and, in case the corer has not penetrated down into the sediment to its full length, when the corer is being pulled out of the bottom. As the pressure is being exerted by the very small amount of water enclosed between the lining and the coring tube, it might be possible to prevent damage to the lining tube by making the space between the lining and the coring tube as small as possible and by obstructing carefully the influx of water into the remaining interstice. When working with a long corer, it is, however, difficult to use wider lining tubes than those described in this paper owing to the difficulty of inserting them into the coring tube or of removing them.

In most cases the underpressure within the lining is due to the friction between the sediment and the lining, and as the underpressure thus produced is not very great the lining tubes will only yield slightly, the section becoming slightly oval. As no great deformation can be allowed the lining tubes should be examined after each coring operation and rejected if necessary.

If the corer does not penetrate into the sediment to its full length, a rather high underpressure may be produced in the lining tubes during the first stage of the heaving, as previously mentioned. Then the piston will find itself at a certain distance below the top of the coring tube, when the corer has stopped. As soon as hauling begins the pressure below the piston will decrease considerably and that will go on until the piston is stopped at the top of the tube. Then the underpressure may cause the core to break into several sections as referred to above, water leaking in at the joints of the lining tubes, but it may also make the lining tubes

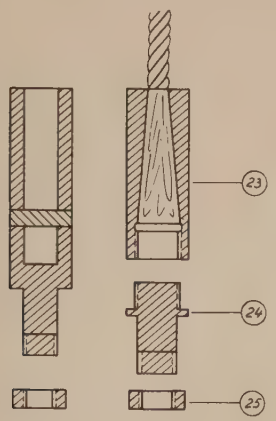

Fig. 19. Component parts of the piston.

oval, or even make them collapse completely. Obviously the brass lining is more apt to give in under the strain, but even stainless steel tubes have often assumed an oval form and, sometimes, collapsed in the circumstances referred to. The damage to the core here mentioned is sometimes very serious and I have tried to prevent it in various ways. One expedient is to disconnect the piston from the wire before hauling begins. I have devised such a piston after the cruise of the »Albatross» was finished, and it will be described in the paragraph dealing with the piston.

The piston is shown in Fig. 19 in two slightly different types. In one of them (to the left) the piston rope has a spliced loop, and it is fastened to the piston by means of a bolt through the loop. In the other type (to the right) the rope is fused to the piston, which makes it possible to use a thicker rope than with the other type. The rope runs up through the tube, and it is fastened to the eye of the lever stand.

The bulk of the piston has a diameter 1 mm less than that of the lining tube, and only the packings fit closely in the lining tube. The packings consist of a series of circular leather clips with slightly smaller brass plates between them. In the centre they have holes for an axial bolt and they are fastened to the bolt with a nut firmly tightened. The bolt is furnished with screw-threads at its upper end corresponding to female threads in the top-piece of the piston.

As soon as the pilot weight has reached the bottom the coring tube with the drive weights at its top will slip off the release mechanism and descend into the mud. If the tube is too heavily loaded, which will very often be the case, the piston will get a violent kick when the top of the coring tube has come down to the piston, which will then strike against the piston catch. As the weight of the corer may be as much as 1,500 kg, this involves an extra strain on the piston and on the piston rope, especially as the corer may have a considerable velocity at the moment of the impact. When the corer is being hoisted, its whole weight will rest on the piston, and to this will be added the force necessary to pull the corer out of the bottom which sometimes may be quite considerable. Occasionally the corer may be released unintentionally before reaching the bottom, so that the piston and the piston rope will be exposed to a very considerable jerk, especially if such a mischance should occur not very far from the surface. It is advisable, therefore, to make the piston

Fig. 20. The piston attached to the piston rope.

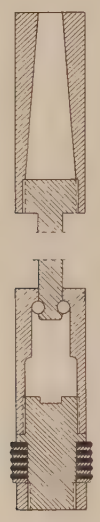

Fig. 21. Device to disconnect the piston from the rope if the corer does not penetrate into the bottom to its whole length.

and its rope as strong as possible. As a rule the type of piston should be used where the rope is fused to the piston, which makes it possible to use a 14 mm rope.

As mentioned above I have modified the piston so as to make it possible to disconnect it from the wire before hauling begins, if the corer does not penetrate into the sediment to its full length. This was made in order to prevent the considerable damage to the core brought about by the underpressure produced below the piston during the first stage of the heaving, which often caused the core to break into several sections. The piston is divided into two parts. The upper part has a permanent connection to the wire, in the same way as the piston described above, but it is not fitted with packings. The lower part carries the same leather packings as described above. The two parts of the piston are connected to each other by steel balls in the way indicated by Fig. 21. As long as the wire is tight the balls will remain in the position they have in Fig. 21, and the piston will operate in the ordinary way. If the wire is made slack after the corer is released and has come to a standstill without penetrating into the bottom to its full length, a lead weight fastened to the upper part of the piston will make this part of the piston move downwards a few centimetres. Then the balls will fall out of their positions and the lower part of the piston with the packings will be disconnected from the upper part of the piston. When the hauling begins, the lower part of the piston will remain stationary, while the upper part is moved up to the top of the tubing. As there are no packings in the upper part of the piston, it does not fit tightly in the tubing and the water can pass it freely. Therefore no underpressure will arise in the tubing, and especially not above the sediment sample, during the heaving.

The counterweight consists of iron cylinders (item 31) suspended from a bar as shown in Fig. 5. The bar (item 30) is connected to the coring tube by means of a short tube in the middle of it. In this manner the centre of gravity of the counterweight will be located to the axis of the coring tube, and the corer will keep an accurately vertical position when suspended from its eye. That would not have been the case if the counterweight had hung vertically below its loop in the lever. Then the coring tube makes a small angle with the vertical, which will increase the risk of the corer being upset when slipping off the lever.

When the corer is going down into the sediment, the bar supporting the counterweight will settle down on the bottom or, possibly, hang immediately above the bottom. When the corer is being hoisted, the bar will keep near the top of the tube and may even carry the whole weight of the corer, or part of it, if the ropes are suitably adjusted. Thus the strain on the piston can be considerably reduced. When taking the corer on board it is a great convenience to be able to hoist the apparatus by the counterweight rope, as the operations cannot be performed by means of the piston rope without this being sharply bent.

A Sampler with a Wide Coring Tube

For many purposes, e. g. radioactive analysis, it is valuable that the diameter of the core is very large, which makes it possible to study very thin layers, provided it is possible to observe the curvature of the strata. Professor PETTERSSON therefore ordered a core sampler with a great width to be manufactured. As there is no principle difference between this corer and the one discussed in the preceding paragraph, it need not be described in detail. The release mechanism and the drive weights were unchanged. The coring tube had an external diameter of 120 mm, a wall thickness of 6 mm, and a length of 6 m. The size of the cutting nose was increased correspondingly and had an external diameter of 140 mm. In view of the moderate wall thickness of the coring tube this was fitted with male screw-threads at its lower end, and the cutting nose with female screw-threads. The core catcher was similar to the one previously described. The lining consisted of six brass tubes with a length of 1 m each, an internal diameter of 90 mm, and a wall thickness of 3 mm. They were joined to each other by means of collars.

Only one corer with these dimensions had been manufactured prior to the Swedish Deep-Sea Expedition. Unfortunately it was lost the very first time we used it, because the cable broke (vide p. 79). A new corer with the same dimensions was manufactured on board the »Albatross» by Mr. JONASSON, who was the mechanician of the expedition. This corer was used at many occasions and worked in a most satisfactory way.

The Free-Fall Principle

Apart from the fact that the free-fall principle is a necessary complement to the piston principle, the free-fall principle makes it possible to diminish the drive weight of the corer as compared with a gravity corer that is being lowered into the mud. This is because the potential energy of the free-fall corer is converted into useful work to a higher degree than in the case of a permanently suspended core sampler.

In fact, if a core sampler is being lowered into the mud, the tension of the cable is equal to the weight of the core sampler in water at the moment the apparatus strikes the bottom and as the corer goes deeper down the tension will diminish and keep equal to the difference between the weight of the apparatus in water and the resistance due to the sediment. Therefore the potential energy of the core sampler is divided into two parts, one being wasted on useless work carried out on the cable, and the other being converted into useful work overcoming the resistance of the sediment. From the moment the resistance of the sediment is equal to the weight of the corer in water the tension in the cable is zero, and the further penetration of the corer is dependent on its kinetic energy, which will have remained constant until this moment. The kinetic energy corresponding to the relatively small unwinding speed will not be able to sustain the motion for long. As shown by the present writer (KULLENBERG 1947) less than 50 % of the potential energy available will be made useful when an ordinary gravity core sampler is being lowered into the bottom.

In the case of a free-fall corer a higher percentage of the potential energy available at the moment the corer strikes the bottom will be converted into useful work, as that part of it which is not consumed in overcoming the resistance of the sediment and the drag of the water will be converted into kinetic energy. The velocity of the core sampler therefore increases until the sum of the resistance due to the sediment and to water friction equals the weight of the core sampler in water, so that thanks to the increased kinetic energy the tube is able to penetrate to a greater depth. Further, it is possible to give the apparatus a high initial velocity by releasing it at an adequate height above the bottom. When this is done

there must be corresponding slack of the piston rope coiling it and securing adjacent coils by means of a thin string in order to prevent kinking (KULLENBERG 1947; SILVERMAN and WHALEY 1950). However, as the corer should always be released at least one metre above the bottom, the initial velocity will in any case be sufficiently high. In fact, as will be shown presently, there is very little to be gained by increasing the drop of the corer beyond 1 m. This appears obvious in the case of a long corer (10—20 m), the centre of gravity of which is situated several metres above the lower end of the tube. Thus, the centre of gravity of a 15 m corer weighing 1,200 kg is situated 15 m above the lower end of the tube, i. e. immediately below the drive weights. Therefore, the relative gain in potential energy by the increase of the drop by 2 or 3 m is quite small. Owing to the loss of energy due to water friction during the free fall, the gain in effective energy will be still smaller. HVORSLEV and STETSON had their gravity corer released when the lower end of the tube was about 3 m above the bottom, whereas the present writer found it unnecessary to make the drop more than 1 m which, however, makes no essential difference between the two methods.

Before treating the motion of the piston corer after the lower end of the tube has reached the bottom, let us consider the free fall of the corer in water. If m = the mass of the corer, d its mean density, k the drag coefficient, and x the distance covered by the corer from the moment it was released till the moment t, the equation of motion is

$$m \frac{d^2 x}{dt^2} = mg \left(1 - \frac{1}{d}\right) - k \left(\frac{dx}{dt}\right)^2 \qquad (1)$$

The unreeling speed being v_0, and the speed of the corer at the moment t being v, we find

$$v^2 = \left[v_0^2 - \frac{mg}{k}\left(1 - \frac{1}{d}\right)\right] e^{-\frac{2kx}{m}} + \frac{mg}{k}\left(1 - \frac{1}{d}\right) \qquad (2)$$

The unreeling speed does not perceptibly influence the final velocity of the corer. The average speed in the final stage of descent during the Swedish Deep-Sea Expedition was generally $v_0 = 70$ cm/sec. The average density of a corer consisting of steel and lead is about 10 g/cm³.

The drag of the corer was underrated in the theory of the free-fall corer given in 1947 (KULLENBERG 1947). The diameter of the drive weights being 40 cm, their drag will be 700 v^2 dynes. Further, the skin friction to the coring tube has to be considered. The longitudinal drag coefficient of a cylindrical surface was determined during the Swedish Deep-Sea Expedition (KULLENBERG 1951) by measuring the tension in a long sable, when it was lowered at a speed of 100 m/min, and also as it was hoisted at the same speed, half the difference giving the drag of the cable. The longitudinal drag per cm² of a long cylindrical surface was found to be about 0.012 v^2 dynes. Accordingly the skin friction to the tubing is about 300 v^2 dynes with a 10 m corer, 500 v^2 dynes with a 15 m corer, and 700 v^2 dynes with a 20 m corer. In view of the eddy formation at the couplings between the sections of the tubing, and at other projecting details of the corer, we add 100 v^2 dynes. Accordingly, the total drag is about 1,100 v^2, 1,300 v^2, and 1,500 v^2 dynes respectively for a corer of 10 m, of 15 m, and of 20 m.

M. SILVERMAN and R. C. WHALEY (1950) devised a very handy piston corer adapted for shallow water sampling. The diameter of the coring tube being 57 mm, the cylindrical surface of a 6 m long tube is 10,800 cm². Accordingly the skin friction of the coring tube should be 140 v^2 dynes. The drive weights seem to have a diameter of about 28 cm, a weight of 250 pounds, and a height of about 19 cm. The drag due to the weights is about 350 v^2 dynes so that the total drag of the corer is 500 v^2 dynes. We assume the total weight of the corer to be 165 kg.

Using equation (2) the velocity of the four corers here mentioned has been computed as a function of the drop (Fig. 22). The three long corers (10 m, 15 m and 20 m) keep very much the same velocity, the difference between the 10 m corer and the 20 m corer being only 0.4 m/sec after a drop of 5 m. The highest velocities these corers can attain when falling through water, are 8.5 m/sec, 9.0 m/sec and 9.4 m/sec respectively. The velocity of the 6 m corer of SILVERMAN and WHALEY is equal to that of one of the heavier corers at a drop of 1 m, but lags behind as the drop becomes greater. The maximum velocity of this corer is 5.5 m/sec and the velocity obtained after a drop of 1.5 m is 4.2 m/sec, which proves that a still higher drop serves no useful purpose.

In order that a drop of more than 1 m shall be of advantage the column of drive weights should be streamlined. Even then a high drop does not present a great advantage owing to the skin friction of the tube itself.

We shall now study the velocity of the corer when it is penetrating into the bottom. The resistance made by the sediment is almost completely due to the friction of the cylindrical surface of the tube. The friction per unit area of the tubing may increase with increasing depth in the sediment, especially in shallow water. In order to make the calculus simple we assume the friction f dynes/cm² to be constant at any given place, though of course f may vary within wide limits according to the character of the sediment. Denoting by r dynes/cm the frictional resistance to a tube with the diameter ϕ we have $r = f \cdot \pi \phi$. Then the equation of motion of the piston core sampler when it is going down into the bottom is

$$m \frac{d^2 x}{d t^2} = mg \left(1 - \frac{1}{d}\right) - k \left(\frac{dx}{dt}\right)^2 - rx \qquad (3)$$

x being the depth of penetration. We find the velocity of the core sampler, $v = \frac{dx}{dt}$, as a

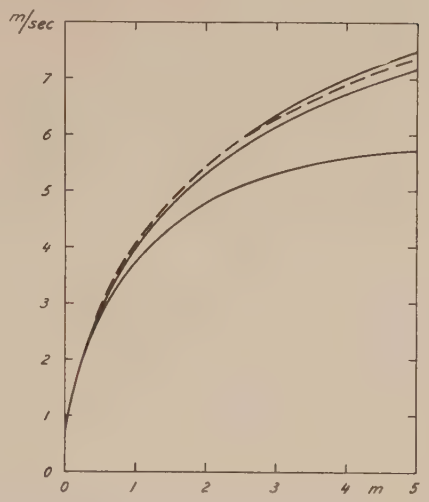

Fig. 22. Diagram showing the velocity of the corer during the free fall as a function of the drop. Unreeling speed 0.7 m/sec. Weight 1,500 kg, asymptotique velocity 9.4 m/sec; weight 1,200 kg, asymptotique velocity, 9.0 m/sec; weight 900 kg, asymptotique velocity 8.5 m/sec, weight 200 kg, asymptotique velocity 6.0 m/sec.

function of the depth of penetration, v_0 denoting the initial velocity, i. e. the velocity of the corer in the moment the lower end of the tube strikes the bottom.

$$v^2 = \left[v_0^2 - \frac{mg}{k}\left(1 - \frac{1}{d}\right) - \frac{mr}{2k^2}\right] e^{-\frac{2kx}{m}} + \frac{mg}{k}\left(1 - \frac{1}{d}\right) + \frac{mr}{2k^2} - \frac{rx}{k}. \qquad (4)$$

Here we have disregarded the possibility that the resistance of the sediment is dependent on the velocity of the corer. We have also disregarded the advantage derived from the use of a mouth-piece with a greater width than the coring tube, which should diminish the friction, especially when the velocity of the corer is high.

Taking for an example $f = 4 \cdot 10^4$ dynes/cm², i. e. a resistance of about 100 kgp/m in the case of a tube with an outside diameter of 80 mm, we have $r = 10^6$ dynes/cm. Here we disregard the fact that the drag is increased by the pressure exerted on the piston stop by the water within the coring tube being forced to leave the tube. On the other hand we do not take into account the decrease in

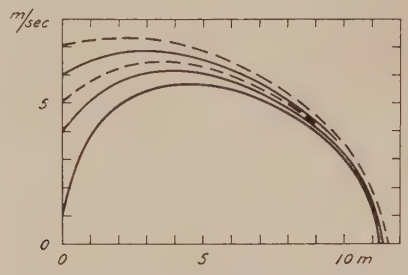

Fig. 23. Diagram showing the velocity of the corer when going down into the sediment. Weight 900 kg, frictional resistance $4 \cdot 10^3$ dynes/cm², initial speed of the corer (i. e. the speed in the moment the lower end of the coring tube strikes the bottom) 1 m/sec, 4 m/sec, 5 m/sec, 6 m/sec, and 7 m/sec.

frictional resistance of the water due to the fact that the length of the tubing exposed to the water is successively diminished. Thus, we assume the drag of the corer to be the same as during the free fall in water before the tube has touched the bottom.

Using eq. (4), the velocities of the corers previously treated have been computed as functions of the depth of penetration, the initial velocity of the three long corers being assumed to be 4 m/sec, 5 m/sec, 6 m/sec, and 7 m/sec. With the 6 m corer of SILVERMAN and WHALEY the initial velocity has been assumed to be 3 m/sec, 4 m/sec, and 5 m/sec. With this corer the computation has been made with two different sediments, viz. $f = 4 \cdot 10^4$ dynes/cm², making $r = 7 \cdot 10^5$ dynes/cm, and $f = 2 \cdot 10^4$ dynes/cm² making $r = 3.5 \cdot 10^5$ dynes/cm.

The diagrams giving the velocity of the corer when it is going down into the bottom of the

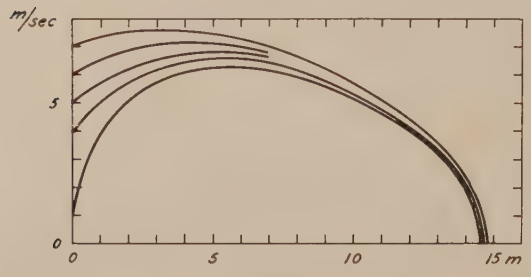

Fig. 24. Diagram showing the velocity of the corer when going down into the sediment. Weight 1,200 kg, frictional resistance and initial speed as in Fig. 23.

sea (Fig. 23—26) make it clear that *the length of the core cannot be increased by giving the corer a higher drop than 1 m.* The three heavy corers will get an initial speed of 4 m/sec, if the drop is 1 m, and 7 m/sec, if the drop is 4—4.5 m. The change of the initial speed from 4 m/sec to 7 m/sec will make the core about 25 cm longer, which *firstly* has little importance in the case of 10—20 m long cores and *secondly* can more easily be obtained by increasing the weight of the corer by about 20 kg. It should be remembered that the preceding computations are based on the assumption that the »specific resistance» f dyn/cm², of the sediment does not increase with the depth below the sediment surface. Very often, and especially in shallow water, the upper sediment layers are less compact than the deeper layers, and the core length gained by increasing the drop is even smaller than when the resistance is uniform. Such being the case, it serves no useful purpose but involves an unnecessary risk to allow the corer a higher drop than 1—1.5 m, at least when the depth of the sea is not very great. As we shall see later, there may be a reason to allow the corer a higher drop at ocean depths.

If the corer is released immediately above the bottom, the initial speed will be about 1 m/sec, which requires a drop of less than 3 cm if the speed is 70 cm/sec. If the initial speed is high, the velocity only rises slowly after the tube has reached the bottom of the sea. The higher the initial speed, the sooner the velocity passes through a maximum. If the initial speed is low, for instance 1 m/sec, the velocity increases more rapidly and soon becomes almost as high as in the case of a high initial velocity. It is interesting to note that even in this extreme case the depth of penetration is practically the same one as when the corer is allowed a drop of 4 m or more, giving it an initial speed of 7 m/sec. Though this clearly demonstrates that it is useless to allow the corer a high drop, one should, on the other hand,

not make the drop too small, anyhow not much less than 1 m. In fact, in a very soft bottom the release may be delayed because the pilot weights sink into the bottom, which is one reason why it is necessary to suspend the pilot weights sufficiently far below the lower end of the tube to make sure that the corer is released before striking the bottom. Another reason for giving the corer a high initial speed by allowing it a drop of 1 m, is the possibility that the bottom is covered with a layer of sand or shells, or as is sometimes the case in great depths, is covered with a hard crust. In such cases the corer will topple over, if the initial speed is small, whereas it is able to penetrate the hard crust, if it is not too thick, and can penetrate a very thick layer of sand, if it has a high initial speed, which prevents it from toppling over.

With a short corer, such as the one described by SILVERMAN and WHALEY, the relative gain in *potential* energy by using a high drop is considerably higher than with a long corer. However, with a short corer the drag is higher relatively to the weight than in the case of a long corer, *and the loss of energy due to the drag eliminates almost completely the potential energy gained by a high drop.* In a sediment, the specific resistance of which is $4 \cdot 10^4$ dynes/cm², a SILVERMAN-WHALEY corer weighing 165 kg should obtain a 3.3 m long core, if the initial velocity is 3 m/sec, corresponding to a drop of 0.6 m (Fig. 26). If the initial velocity is 5 m/sec, corresponding to a drop of 3.0 m, the length of the core should be 3.5 m. The same increase of the length of the core could be obtained by increasing the weight of the corer by about 10 kg. Therefore with this corer, the only advantage obtained by increasing the drop from 0.6 m to 3.0 m would be that the corer can be made 10 kg lighter. In a sediment with a specific resistance of $2 \cdot 10^4$ dynes/cm² the advantage is smaller. Then the core would be only 7 cm longer if the initial velocity is 5 m/sec than if the initial velocity is 3 m/sec; in both cases the core should be about 5.8 m long. *Obviously, with a short corer, it will be an advantage to use stream-lined drive weights.*

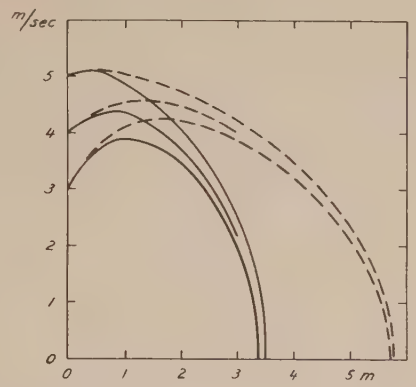

Fig. 26. Diagram showing the velocity of a corer with the dimensions given by Silverman and Whaley when going down into the sediment. Weight 165 kg, frictional resistance $4 \cdot 10^4$ dyne/cm² (fulldrawn curves) and $2 \cdot 10^4$ dyne/cm² (dashed curves). Initial speed 3 m/sec, 4 m/sec, and 5 m/sec, corresponding to a drop in water of 0.6 m, 1.3 m, and 3 m respectively, if the unreeling speed is 0.7 cm/sec

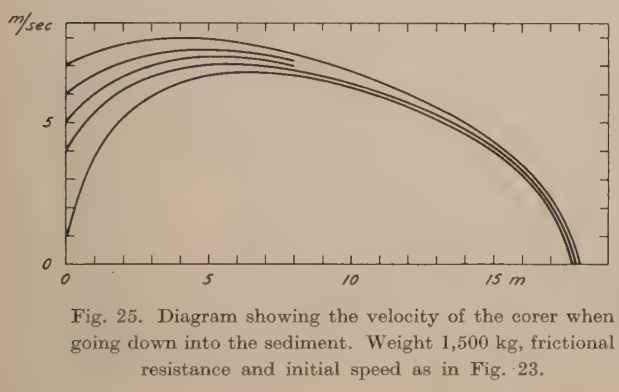

Fig. 25. Diagram showing the velocity of the corer when going down into the sediment. Weight 1,500 kg, frictional resistance and initial speed as in Fig. 23.

The Cable

Technical data

The »Albatross» carried three long cables, one of which was 7,600 m long and the other two 8,100 m.

The 7,600 m cable was made by the *Swedish Wire Rope Company, Ltd. Hellefors*, and was of the Type *Warrington No 32* with right hand ordinary lay, 6 strands with 19 wires each (12 round 6 round 1), and a hemp main core. It was a tapered line consisting of five uniform

sections with the diameters 12, 14, 16, 18 and 20 mm. The sections were not joined by splicing, but each wire in one section was joined to the corresponding wire in the subsequent section by electrical welding, the diameter of the cable being increased from one section to the next one by increasing the diameter of the wires, leaving the number of the wires unchanged. The distance between the subsequent wire joints was about 40 cm and the conical portions of the cable between adjoining uniform sections were about 50 m in length. The breaking strain of the wires was about 190 kp/mm². With a load of 1,500 kg the safety factor was 3.35, the length of each uniform section being so determined that its own weight plus the load attached equalled the proper working load. The factor of bouyancy was considered with regard to the cable, but not with regard to the load. The net weight of the cable was 6,700 kg. It was not galvanized but had been thoroughly lubricated by the manufacturer. The length, weight, and breaking strain of each uniform section of the cable is given in Table 1.

The 8,100 m cables were made by *Wright's Ropes Ltd, Birmingham*. Each was a tapered rope consisting of three uniform sections with the diameters 12, 16 and 20 mm. It consisted of three strands, the number of wires in each strand being 19 (12 round 6 round 1) in the 12 mm section, 37 (18 round 12 round 6 round 1) in the 16 mm section, and 61 (24 round 18 round 12 round 6 round 1) in the 20 mm section. The diameter of the wire was 1.12 mm and it had a tensile stress of approximately 220 kp per square mm, and was heavily galvanized. Starting at the thicker and upper end of the cable, the diameter fell from 20 mm to 16 mm by cutting out, in each strand, the 24 wires belonging to the outer layer, and in the same way the diameter was brought down from 16 mm to 12 mm by cutting off, in each strand, the 18 wires belonging to the next layer. Thus, the wires entering into the thinnest part of the cable extended from one end of the cable to the other. The conical parts between the adjoining uniform sections were only one or two meters long. The net weight of the cable was 7,500 kg. With a load of 1,500 kg the safety factor was 3.6. The length, weight, and breaking strain of each uniform section of the cable are given in Table 2.

TABLE 1.

Trawling cable delivered by the *Swedish Wire Rope Company, Ltd.*

Diameter	Medium diam. of wires	Length	Weight	Breaking strain
12 mm	.79 mm	2,500 m	.534 kg/m	8,900 kp
14	.92	1,490	.727	12,100
16	1.06	1,350	.950	15,800
18	1.19	1,160	1.20	20,000
20	1.33	1,100	1.48	24,600

TABLE 2.

Diameter	Length	Weight	Breaking strain
12 mm	3,060 m	.48 kg/m	
16	2,850	.94	
20	2,190	1.52	34,000 kp

Elastic vibrations

The immobilization of the piston after the corer has been released is obviously a very important feature in the function of the piston corer. When working in shallow water the immobilization of the piston presents no difficulty, as the piston will stop simultaneously with the winch. In deep water, however, the rather complex behaviour of the long sounding cable has to be considered. At a depth of 200 m the elastic lengthening of the cable due to the weight of the corer, is insignificant. At a depth of 6,000 m, on the other hand, the elastic lengthening of the cable due to the weight of the corer may amount to 10 m, and the stretching caused by the weight of the cable itself may amount to 15 m, i. e. the total elastic distention of the cable itself may amount

to 25 m, which gives rise to a very considerable displacement of the piston due to elastic vibrations of the cable. *Therefore, it is not possible to immobilize the piston completely at a great depth.* To be able to judge the motion of the piston and find out how to achieve as high a degree of immobilization as possible, it is necessary to study the elastic vibrations of the cable.

Longitudinal elastic vibrations of the sounding cable will be started at the moment the corer is released and, also, at the moment the lowering of the cable is stopped. In fact, as soon as the cable has been freed from the weight of the corer it will contract and pull the piston upwards. Obviously the vibrations thus created will affect the piston irrespective of whether the depth of the sea be great or small, unless it is very small. Further, when the lowering of a long cable is suddenly stopped, the lower end of the cable does not respond at once but will continue its motion for one or two seconds without change of velocity. Thus another set of vibrations is started. If the corer has penetrated with its whole length before the stop has made itself felt at the lower end of the cable, the last mentioned vibrations will be of no account as far as the movement of the piston is concerned. Therefore, the measures taken on board the ship as soon as the dynamometer indicates that the corer has been released cannot affect the piston during the critical stage of events provided the depth is above a certain limit, depending on the length of the corer, say 4,000 m with a 10 m corer, and 6,000 m with a 15 m corer.

The differential equation of longitudinal elastic vibrations in a cable of a uniform thickness is

$$\frac{\partial^2 u}{\partial t^2} = \frac{E}{\varrho} \frac{\partial^2 u}{\partial x^2} \qquad (5)$$

u denoting the displacement, t the time, x the (vertical) coordinate, E the elastic coefficient, and ϱ the density of the cable. It should be understood that neither the elastic coefficient, nor the »density» of the cable, are equal to the corresponding constants of steel.

We will consider a long resting cable with a heavy load suspended at its lower end. The load will cause the cable to be lengthened a certain amount. When, at $t = 0$, the load is suddenly removed the cable will shorten, and a longitudinal elastic wave will start at the lower end of the cable. Putting $x = 0$ at the top of the cable, and $x = L$ at the lower end of the cable we get the following boundary conditions, P denoting the weight of the load, and S the tension in the cable.

$$x = 0 \qquad : u = 0 \qquad (6\,a)$$

$$t = 0,\ x \neq L\ :\ S = P,\ \frac{\partial u}{\partial t} = 0 \qquad (6\,b)$$

$$t = 0,\ x = L\ :\ S = 0 \qquad (6\,c)$$

Putting $u = \varphi(x)\,\psi(t)$ we get

$$\frac{\varrho}{E}\,\frac{\psi''(t)}{\psi(t)} = \frac{\varphi''(x)}{\varphi(x)} = -\nu^2, \qquad (7)$$

ν being a constant.

Putting $\frac{E}{\varrho} = c^2$ we get

$$\varphi(x) = A_1 e^{i\nu x} + A_2 e^{-i\nu x} \qquad (8)$$

$$\psi(t) = B_1 e^{i\nu c t} + B_2 e^{-i\nu c t} \qquad (9)$$

Owing to the boundary conditions $u_{x=0} = 0$ and

$$\left(\frac{\partial u}{\partial t}\right)_{t=0} = 0$$

we find $A_2 = -A_1$ and $B_2 = B_1$, whence

$$u_\nu = a_\nu \sin \nu x \cdot \cos \nu c t \qquad (10)$$

The »Eigenwerte» ν are determined by the boundary condition (6 c).

As $S = Eq \frac{\partial u}{\partial x}$, then $\left(\frac{\partial u}{\partial x}\right)_{x=L,\,t\ 0} = 0$,

whence

$$\nu\, a_\nu \cos \nu L = 0 \qquad (11)$$

$$v\,L = \frac{(2\,n+1)\,\pi}{2},\quad n = 0, 1, 2 \ldots\ldots \quad (12)$$

$$u_n = a_n \sin\frac{(2\,n+1)\,\pi}{2\,L}\,x \cdot \cos\frac{(2\,n+1)\,\pi}{2\,L}\,c\,t \quad (13)$$

$$u = \sum_{n=0}^{\infty} a_n \sin\frac{(2\,n+1)\,\pi}{2\,L}\,x \cdot \cos\frac{(2\,n+1)\,\pi}{2\,L}\,c\,t \quad (14)$$

The coefficients a_n are determined by the boundary condition $S_{t=0} = P$, whence

$$\left(\frac{\partial\,u}{\partial\,x}\right)_{t=0} = \frac{P}{Eq} \quad (15)$$

By derivation of (14) we get

$$\frac{\partial\,u}{\partial\,x} = \frac{\pi}{2\,L}\sum_{0}^{\infty}(2\,n+1)\,a_n \cos\frac{(2\,n+1)\,\pi}{2\,L}\,x \cdot \cdot \cos\frac{(2\,n+1)\,\pi}{2\,L}\,c\,t \quad (16)$$

Putting $t = 0$ and applying (15) we get

$$\sum_{0}^{\infty}(2\,n+1)\,a_n \cos\frac{(2\,n+1)\,\pi}{2\,L}\,x = \frac{2\,L\,P}{\pi\,Eq} \quad (17)$$

$$(2\,n+1)\,a_n \int_0^L \cos^2\frac{(2\,n+1)\,\pi}{2\,L}\,x\,dx = = \frac{2\,L\,P}{\pi\,Eq}\int_0^L \cos\frac{(2\,n+1)\,\pi}{2\,L}\,x\,dx \quad (18)$$

$$a_n = \frac{8\,L\,P}{\pi^2\,Eq}\,\frac{(-1)^n}{(2\,n+1)^2} \quad (19)$$

$$u = \frac{8\,L\,P}{\pi^2\,Eq}\sum_{0}^{\infty}\frac{(-1)^n}{(2\,n+1)^2}\sin\frac{(2\,n+1)\,\pi}{2\,L}\,x \cdot \cdot \cos\frac{(2\,n+1)\,\pi}{2\,L}\,c\,t \quad (20)$$

$$u = \frac{4\,L\,P}{\pi^2\,Eq}\sum_{0}^{\infty}\frac{(-1)^n}{(2\,n+1)^2}\left[\sin\frac{(2\,n+1)\,\pi}{2\,L}(x+c\,t) + + \sin\frac{(2\,n+1)\,\pi}{2\,L}(x-c\,t)\right] \quad (21)$$

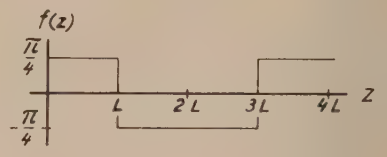

Fig. 27. Diagram representing the function

$$f(z) = \sum_{0}^{\infty}\frac{(-1)^n}{2\,n+1}\cos\frac{(2\,n+1)\,\pi}{2\,L}\,z$$

$$\frac{\partial\,u}{\partial\,t} = \frac{2\,P}{\pi\,q\sqrt{E\,\varrho}}\sum_{0}^{\infty}\frac{(-1)^n}{2\,n+1}\left[\cos\frac{(2\,n+1)\,\pi}{2\,L}(x + + c\,t) - \cos\frac{(2\,n+1)\,\pi}{2\,L}(x-c\,t)\right] \quad (22)$$

$$\frac{\partial\,u}{\partial\,t} = \frac{2\,P}{\pi\,q\sqrt{E\,\varrho}}\,(\Sigma_1 - \Sigma_2) \quad (22\,a)$$

The expression

$$f(z) = \sum_{0}^{\infty}\frac{(-1)^n}{2\,n+1}\cos\frac{(2\,n+1)\,\pi}{2\,L}\,z$$

is the Fourier development of the periodic function represented by Fig. 27, the period being $2\,L$, and the value of the function being alternatingly $+\frac{\pi}{4}$ and $-\frac{\pi}{4}$.

Hence:

$$\begin{aligned} &o < x + c\,t < L \text{ will give } \Sigma_1 = \frac{\pi}{4}\\ &L < x + c\,t < 3\,L \qquad \Sigma_1 = \frac{\pi}{4}\\ &L > x - c\,t > -L \qquad \Sigma_2 = \frac{\pi}{4}\\ &-L > x - c\,t > -3\,L \qquad \Sigma_2 = \frac{\pi}{4} \end{aligned} \quad (23)$$

and so:

$$c\,t - L < x < L - c\,t \text{ will give } \frac{\partial\,u}{\partial\,t} = 0, \quad (24\,a)$$

$$L - c\,t < x < L + c\,t \text{ will give } \frac{\partial\,u}{\partial\,t} = = -\frac{P}{q\sqrt{E\,\varrho}} \quad (24\,b)$$

This implies the existance of a discontinuity at $x = L - ct$, above which $\frac{\partial u}{\partial t} = 0$, and below which $\frac{\partial u}{\partial t} = -\frac{P}{q\sqrt{E\varrho}}$. The point of discontinuity, or the wave front, will be situated at $x = L$, i. e. the lower end of the cable, at $t = 0$, i. e. the moment when the cable is released of the load. Then the wave front will run upwards at the velocity $c = \sqrt{\frac{E}{\varrho}}$, i. e. the velocity of sound in the cable. The whole section of the cable situated below the wave front will move upwards at the uniform velocity $v = \frac{P}{q\sqrt{E\varrho}}$, whereas the portion of the cable situated above the wave front will be at rest.

The wave front will arrive at the top end of the cable at the time $t = L : c$. After that moment the discontinuity will appear at $x = ct - L$, i. e. the wave front will be reflected and run downwards at the same velocity as before. As before the eq. $\frac{\partial u}{\partial t} = 0$ is valid above the wave front, and $\frac{\partial u}{\partial t} = \frac{P}{q\sqrt{E\varrho}}$ is valid below the wave front. When arriving at the lower end of the cable the wave front will be reflected once more, and so it will go on running up and down the cable at the velocity of sound. For our problem, however, only the first stage of the procedure is of real importance, i. e. what happens when the wave front is running up the cable for the first time, though it may be necessary to study what happens when the wave front is running down the cable for the first time after having been reflected at the top of the cable. We will consider the tension in the cable during these two stages.

By derivation of (21) and using the same abbreviations as in (22 a) we get

$$S = \frac{2P}{\pi}(\Sigma_1 + \Sigma_2) \qquad (25)$$

Obviously, when the wave front is running upwards for the first time, the tension will be zero below the wave front, and it will be equal to P above the wave front. During the second stage, when the wave front is running down the cable after having been reflected at the top end, the tension or rather, the part of the tension produced by the elastic forces, will be equal to $-P$ above the wave front and zero below the front. Whereas it is quite possible for the tension produced by elastic forces to be negative as far as the tension produced by the weight of the cable exceeds that produced by the elastic forces numerically, it is not possible, when that is not the case because then a long portion of the cable should be compressed longitudinally. Such a compression would be possible in a cylinder with a sufficiently high rigidity, but it is not possible in a cable with practically no rigidity. Therefore, as soon as the wave front, running downwards, arrives at the point where the tension produced by the weight of the cable is P, then the tension produced by elastic forces, keeping a negative sign, will be numerically the same as the weight of the cables below the wave front, and the resulting tension of the cable will be zero. Then part of the wave energy will be transformed into kinetic energy carried by *transversal* vibrations of the cable, and the energy thus transformed will quickly be absorbed by the water, as the frictional resistance to transversal movements of the cable is very great. So the fact that the cable cannot be longitudinally compressed will tend to diminish the displacement of the lower end of the cable as the elastic wave is returning after having been reflected at the top end.

The net tension at the top of the cable being equal to the weight of the cable *plus* the weight of the corer immediately before the elastic waves arrive at the top of the cable, and being equal to the weight of the cable *minus* the weight of the corer immediately after the elastic wave has arrived at the top of the

cable, the release of the corer will be announced by a sudden decrease of the tension by twice the weight of the corer. The announcement will take place a little later than the release, the time lag being equal to the time required for the elastic wave to travel from the lower end of the cable to its top.

Now let us consider a cable without a load and being lowered at a constant velocity v, the lowering being stopped abruptly at the time $t = o$. The differential equation will be the same as before:

$$\frac{\partial^2 u}{\partial t^2} = \frac{E}{\varrho}\frac{\partial^2 u}{\partial x^2}, \tag{5}$$

but the boundary conditions will change:

$$x = 0 \qquad : u = 0, \frac{\partial u}{\partial t} = 0 \tag{26 a}$$

$$x > 0, t = 0 : u = 0, \frac{\partial u}{\partial t} = v \tag{26 b}$$

$$x = L \qquad : S = 0 \tag{26 c}$$

Putting $u = \varphi(x)\,\psi(t)$ we get as before

$$\varphi(x) = A_1 e^{i\nu x} + A_2 e^{-i\nu x} \tag{8}$$

$$\psi(t) = B_1 e^{i\nu c t} + B_2 e^{-i\nu c t} \tag{9}$$

The boundary conditions (26 a) and (26 b) demand $A_2 = -A_1$ and $B_2 = -B_1$, whence

$$u_\nu = a_\nu \sin \nu x \cdot \sin \nu c t \tag{27}$$

The »Eigenwerte» are determined by (26 c), which implies $\left(\frac{\partial u}{\partial x}\right)_{x=L} = 0$, whence

$$\nu a_\nu \cos \nu L = 0 \tag{28}$$

$$\nu L = \frac{(2n+1)\pi}{2}, \; n = 0, 1, 2 \ldots \tag{29}$$

$$u_n = a_n \cdot \sin \frac{(2n+1)\pi}{2L} x \cdot \sin \frac{(2n+1)\pi}{2L} c t \tag{30}$$

$$u = \sum_0^\infty a_n \cdot \sin \frac{(2n+1)\pi}{2L} x \cdot \sin \frac{(2n+1)\pi}{2L} c t \tag{31}$$

The coefficients a_n are determined by the condition that $\frac{\partial u}{\partial t} = v$ at $t = 0$ (26 b). By derivation of (31) we get

$$\frac{\partial u}{\partial t} = \frac{\pi c}{2L} \sum_0^\infty (2n+1)\, a_n \sin \frac{(2n+1)\pi}{2L} x \cdot \cdot \cos \frac{(2n+1)\pi}{2L} c t \tag{32}$$

$$\sum_0^\infty (2n+1)\, a_n \sin \frac{(2n+1)\pi}{2L} x = \frac{2Lv}{\pi c} \tag{33}$$

$$a_n = \frac{8Lv}{\pi^2 c\,(2n+1)^2} \tag{34}$$

$$u = \frac{4Lv}{\pi^2 c} \sum_0^\infty \frac{1}{(2n+1)^2}\left[\cos \frac{(2n+1)\pi}{2L}(x - - c t) - \cos \frac{(2n+1)\pi}{2L}(x + c t)\right] \tag{35}$$

$$\frac{\partial u}{\partial t} = \frac{2v}{\pi} \sum_0^\infty \frac{1}{(2n+1)}\left[\sin \frac{(2n+1)\pi}{2L}(x - - c t) + \sin \frac{(2n+1)\pi}{2L}(x + c t)\right] \tag{36}$$

$$\frac{\partial u}{\partial t} = \frac{2v}{\pi}(\Sigma_1 + \Sigma_2) \tag{36 a}$$

The expression

$$f(z) = \sum_0^\infty \frac{1}{2n+1} \sin \frac{(2n+1)\pi}{2L} z$$

is the Fourier development of the periodic function represented by Fig. 28, the period being $4L$, and the value of the function being alternatingly $+\frac{\pi}{4}$ and $-\frac{\pi}{4}$.

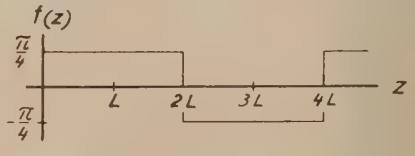

Fig. 28. Diagram representing the function $f(z) = \sum_0^\infty \frac{1}{2n+1} \sin \frac{(2n+1)\pi}{2L} z$

Hence:

$$c\,t < x \qquad \text{will give } \frac{\partial u}{\partial t} = v$$

$$x < c\,t < 2\,L - x \qquad \text{will give } \frac{\partial u}{\partial t} = 0 \quad (37)$$

$$2\,L - x < c\,t < 2\,L + x \text{ will give } \frac{\partial u}{\partial t} = -\,v$$

This implies a discontinuity at $x = c\,t$, above which $\frac{\partial u}{\partial t} = 0$, and below which $\frac{\partial u}{\partial t} = v$. The point of discontinuity, or the wave front, will be situated at $x = 0$, i. e. the top of the cable, at $t = 0$, i. e. the moment when the lowering of the cable is suddenly stopped. Then the wave front will run downwards at the velocity $c = \sqrt{\frac{E}{\varrho}}$, i. e. the velocity of sound in the cable. The portion of the cable situated above the wave front will be at rest, whereas the portion of the cable situated below the wave front will move downwards at the uniform velocity v. The wave front will arrive at the lower end of the cable at the time $t = L : c$. After that moment the discontinuity will appear at $x = 2\,L - c\,t$, i. e. the wave front will be reflected and run upwards at the same velocity as before, the cable being at rest above the wave front and moving upwards at the velocity v below the wave front.

The tension in the cable is given by the equation

$$S = Eq\frac{\partial u}{\partial x} =$$

$$= Eq\frac{2\,v}{\pi\,c}\sum_{0}^{\infty}\frac{1}{2\,n+1}\left[\sin\frac{(2\,n+1)\,\pi}{2\,L}(x + c\,t) - \right.$$

$$\left. - \sin\frac{(2\,n+1)\,\pi}{2\,L}(x - c\,t)\right] \qquad (38)$$

$$S = Eq\frac{2\,v}{\pi\,c}(\Sigma_2 - \Sigma_1) \qquad (38\text{ a})$$

Accordingly, when the wave front is running down and up the cable for the first time, the tension will be zero below the wave front, and it will be equal to $Eqv : c = q\,v\sqrt{E\varrho}$ above the wave front. Hence, a sudden stopping of the lowering will not create a very high tension in the cable.

Immobilization of the Piston

Combined action of two systems of elastic vibrations

When the corer at the end of a long cable is approaching the bottom the cable will be suddenly released from the heavy apparatus at the moment the corer begins to drop. Then the first system of elastic vibrations in the cable will be started. The piston is pulled upwards at a velocity depending on the weight of the corer and on the properties of the cable as expressed by the equation $v = P : q\sqrt{E\varrho}$. If the weight of the corer is small, it is possible to unwind the cable at the velocity v, and then the piston will come to a standstill at the moment the corer falls off the lever. If the disturbing influence of the longitudinal drag of the cable is for the present disregarded, the piston will remain motionless until the elastic wave has travelled up and down the whole cable, running with the velocity of sound. If the lowering is stopped at the moment the first elastic wave arrives at the top of the cable, announcing that the core sampler has reached the bottom, the second system of elastic vibrations will cancel the first one, and the whole cable will be permanently at rest. However, if the weight of the core sampler is not small, the release will cause the cable to shorten itself at such a rate that the cable cannot be unreeled sufficiently rapidly to compensate for its elastic contraction. Further, the influence of the longitudinal drag of the cable will increase, and it is, therefore, impossible to immobilize the piston completely when working with a heavy corer.

Influence of the longitudinal drag of the cable, and other forces

In the discussion set out in the preceding pages the influence of the longitudinal drag of the cable on the elastic vibrations has not been taken into account. Other factors to be considered are, the pressure exercised on the piston by the water leaving the coring tube through the upper exit, and the suction at the same time exercised on the piston from below, owing to the underpressure created by the friction between the core and the lining, and, further, by a possible upward movement of the piston, which should cause a considerable underpressure, due to the resistance from the sediment entering the tube. The capacity of the liner to stand the strain puts a limit to the underpressure, but the space left between the lining and the steel tube being very small, and the water in that space communicating with the outside water by diminutive leaks only, the liner is to a certain extent protected by the steel tube and which admits of a considerable underpressure.

Immediately after the corer has been released, the cable will shorten at the velocity $\frac{P}{q\sqrt{E\varrho}}$, pulling the piston upwards at that velocity minus the unreeling speed. As the elastic wave proceeds upwards in the cable, the tension below the wave front will increase owing to the changed drag of the cable below the wave front. As a consequence the tension discontinuity at the wave front is continually diminished, which, in its turn, will reduce the velocity discontinuity at the wave front. The unreeling speed being v_0, the upward velocity of the portion of the cable below the wave front being v, and the tension discontinuity being ΔS, we have approximately:

$$v + v_0 = \frac{\Delta S}{q\sqrt{E\varrho}} \qquad (39)$$

$$\Delta S = P - C_l \Phi x (v^2 + v_0^2) \qquad (40)$$

the distance covered by the elastic wave being denoted x. The diameter Φ in cm, the drag coefficient C_l has been determined as $C_l = 0.037$ (KULLENBERG 1951). *The equations prove that it is not possible to immobilize the piston completely during the whole time required by the corer to penetrate into the bottom.* In fact, if the piston is to be brought to an immediate standstill at the release of the corer, the unreeling speed has to be $v_0 = \frac{P}{q\sqrt{E\varrho}}$ i. e. 2.1 m/sec, 4.2 m/sec, and 6.3 m/sec with a corer weighing 500 kg, 1,000 kg, and 1,500 kg respectively, the diameter of the cable being 12 mm. Taking the case of a corer weighing 1,000 kg the drag of 500 m of the cable should amount to 400 kp before the release of the corer. The corer weighing 900 kg in water, the tension discontinuity should accordingly fall to 500 kp, if the lowest 500 m of the cable were brought to a standstill, which in its turn should change the velocity at which the cable shortens to 2.3 m/sec. Then the piston would move downwards at a high velocity. Apart from this consideration, it is not possible to make the unreeling speed as high as indicated above.

Using equations (39) and (40) the upward velocity v of the lower end of the cable after the release of the corer has been computed for corers weighing 500 kg, 1,000 kg, and 1,500 kg, or 450 kg, 900 kg, and 1,350 kg resp. in water. In Fig. 29 the velocity of the piston is given as a function of the distance travelled by the elastic wave in the cable, described in Table 2. When the elastic wave arrives at the point where the diameter of the cable changes from 12 mm to 16 mm, i. e. when the wave has travelled 3,000 m, part of the wave energy is reflected. To simplify matters we will disregard the reflection. In doing so, we incur a discontinual change of the velocity of the piston at the moment the wave front arrives at the point where the diameter of the cable changes al-

though, as a matter of fact, the velocity changes continually at that moment. (There are moments when the velocity of the piston changes discontinually). The unreeling speed has been assumed to be 0.7 m/sec, which was the speed generally used during the final stage of the lowering.

As demonstrated by Fig. 29 the piston would move upwards at a high velocity during the free fall of the corer, if no other forces were acting on the cable than the elastic forces and the drag. The velocity should decrease quickly, however, and be comparatively moderate after the elastic wave has reached the 16 mm portion of the cable, i. e. about 0.8 sec after the release of the corer. The high velocity of the piston would cause a serious disturbance of the core. As the velocity is higher in the case of a heavy corer, the weight of the corer should be kept as small as possible. *One possibility to diminish the weight of the corer is to make the drive weights streamlined, which should be done.* As the velocity of the piston is highest in the first stage of the free fall, the injury to the core can be lessened by allowing the corer a high drop. If the corer is allowed a drop of 3 m, 0.8 sec will elapse from the moment of release until the coring tube strikes the bottom of the sea, and meanwhile the elastic wave in the cable has reached the thicker portion of the cable and the velocity of the piston will have diminished considerably. However, during the Swedish Deep-Sea Expedition the corer was not allowed a higher drop than 1 m.

As pointed out above, the water in the coring tube exerts pressure on the piston, retarding its upward movement. Unless the outlet near the top of the tube is very narrow, the pressure on the piston is not high. On the other hand, with a narrow outlet the water in the coring tube should exert a considerable braking force on the corer itself, which is not to be desired. I therefore usually made the area of the water exit 1/3 of the

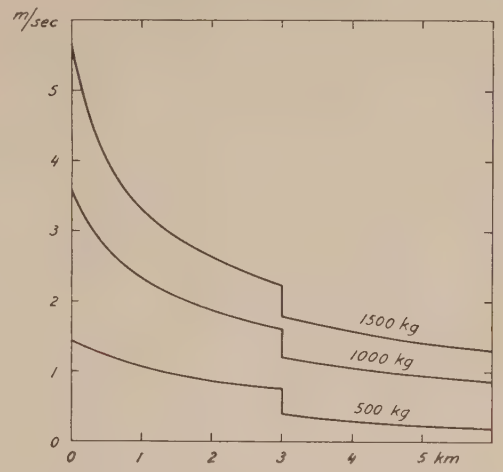

Fig. 29. Diagram showing approximately the upwards directed velocity of the piston as a function of the distance travelled by the elastic wave starting at the lower end of the cable in the moment the corer is released.

sectional area of the lining tube. Then the pressure exerted on the piston, the sectional area of which was 16.6 cm², was approximately 200 w^2 dynes, the velocity of the corer relatively to the piston being w cm/sec. At $w = 600$ cm/sec the force acting on the piston should be $7 \cdot 10^7$ dynes, i. e. about 70 kp, which is by far not sufficient to bring the piston to a standstill.

However, the appearance of the cores makes it probable that there is no appreciable suction as the corer is going down into the bottom. When sharply divided strata occur, the stratification seems to be essentially undisturbed, and wormholes, which are sometimes frequent, are well preserved, which should not have been the case if the sediment had been partly sucked into the corer. It might, therefore, be inferred that the piston is practically immobilized when the corer is going down into the sediment. There may be various reasons for this. One possibility is, that the coefficient of elasticity of the rope delivered by *Wright's Ropes Ltd* may be higher than $7 \cdot 10^{11}$ dynes/cm² which was found to be the coefficient of elasticity of the rope from the *Swedish Steel Line Co., Ltd.* Further, if the piston moves upwards, the

underpressure below the piston will probably rise considerably owing to the resistance exerted by the sediment against being sucked into the tube, thus bringing the piston to a standstill, just as elastic forces would have done if the core had been a rigid body. As even a steel lining tube sometimes becomes slightly oval, and occasionally collapses, the underpressure below the piston is obviously quite high. If it is allowed to rise too much, the strain exerted on the core may become too high. This is sometimes indicated by a stretching of the core, making it slightly more narrow than the lining tube, the vacant space thus created between the core and the lining tube being filled with water leaking in through the joints in the lining tube section. In other instances the core was broken into several pieces and the interspace filled with water.

The uppermost sediment layers are often less compact than the deeper layers, and at the same time the elastic forces pulling the piston upwards are less hampered by the drag of the cable, as the tube is penetrating the uppermost layers. Therefore, the upper part of the core is more exposed to damage by suction than the deeper parts of the core. Further, the upper part of the core has to pass the whole length of the tube as the corer is going down into the bottom, being thus exposed to considerable injury by the friction between the core and the lining tubes. It is, therefore, advisable to take two cores with the piston corer at each station, first using a 5 m long corer, and then using the greatest length deemed possible with regard to the consistency of the sediment. In the case of a 5 m long corer there is no appreciable suction, because the weight of the corer is small, and further, the injury caused by the friction between core and lining tube is small. However, during the Swedish Deep-Sea Expedition, lack of time did not permit more than one core with the piston corer to be taken at each station, but generally the top layer was sampled by means of a short ordinary gravity corer.

The preceding discussion should have made it clear that the problem of immobilizing the piston when working at a great depth is a highly intricate one. It does not seem possible to arrive at definite conclusions by a merely theoretical study of the question. It is, therefore, highly desirable that experiments should be made by taking a series of cores at a deep-sea station with stratified sediments, the weight of the corer being varied between wide limits. Other factors, such as the height of the drop allowed the corer, the unreeling speed, and the area of the water exit should be varied as well. Then a comparison of the depths of identical strata in the cores should give valuable information regarding the accuracy with which the actual sequence of layers *in situ* is represented by the cores.

The Strain on the Cable

Factors adding to the strain

Several circumstances expose the cable to a very considerable strain, which ultimately caused one of them (the Swedish cable) to break. The tension variations due to waves and swell, and the extra force necessary to extract the corer from the bottom of the sea, were carefully considered before the cruise. Further, accidental release of the corer before it had reached the bottom of the sea was anticipated, and at such an accidental release the cable must experience a violent jerk when bringing the heavy corer to a standstill after the corer has acquired a high velocity by free fall of 10—20 m. An unexpected difficulty arose from the design of the winch, which turned out to involve a very great danger to a tapered rope, which could, however, be overcome. A careful consideration of the anticipated risks to the cable decided against the use of accumulators as being unnecessary.

The force necessary to extract the corer from the bottom

This has been discussed in connection with the design of the mouth-piece, or bite, of the piston corer. During the first two months of the expedition a mouth-piece with the same width as the coring tube was used. Though the force necessary to extract the corer was considerable, it did but in few cases rise to a dangerous height, provided that the hauling was started immediately after the corer had been released. This was not always done, however, and on August 30th, 1947, a short delay caused the force to rise to about 3,000 kp, making the total strain at the top of the 12 mm-section of the Swedish cable about 5,000 kp, and reducing for a while the factor of safety to less than 1.8, which greatly endangered the cable. On September 1st, 1947, a few minutes elapsed before the hauling was started, and in consequence the tension in the cable rose above the limit of the dynamometer, which was on that occasion 8,000 kp. The breaking strain of the 12 mm section of the cable being 8,900 kp, the cable broke and the 15.5 m long corer was lost together with 850 m of the cable. The incident made me increase the width of the mouth-piece by about 20 mm, which, according to the experience of KUENEN (1932, 1942) during the Snellius Expedition, reduces the force necessary to extract the corer. After this change had been made, the force in question kept well below a critical value and very often it was barely perceptible.

The action of waves and swell on a cable without a load

The waves and swell causes the ship to roll and pitch. If the ship is standing by, heading the main swell, we can disregard the rolling, and then the vertical movements of any point of the ship are the smaller, the nearer midship the point is situated. Accordingly, the pulley conducting the cable into the sea should be put up as near midship as possible. Assuming the vertical acceleration to change periodically as $a \cdot \sin \frac{2\pi t}{T}$, I measured the vertical movements of the »Albatross» by putting 5 kg on a 10 kg spring-balance, and reading the deviations of the balance. It should be mentioned that the independent vibrations of the spring-balance are much quicker than the pitching of the ship, and, therefore, the deviations of the spring-balance are exclusively due to the vertical acceleration transferred to it by the ship. Only on a few occasions during the expedition did the deviations of the spring-balance exceed $\pm$ 0.75 kg near the pulley conducting the cable into the sea. The load on the balance being 5 kg, this implies a maximal acceleration of $\pm$ 0.15 g. Denoting by u the height of the point in question (the spring-balance, or the pulley), and by T the period of the pitching, we have

$$u = u_0 \sin \frac{2\pi t}{T} \tag{41}$$

$$\frac{d^2 u}{d t^2} = -\frac{4\pi^2 u_0}{T^2} \cdot \sin \frac{2\pi t}{T} \tag{42}$$

Denoting by a_0 the amplitude of the acceleration, we have

$$a_0 = -\frac{4\pi^2 u_0}{T^2}, \qquad u_0 = \frac{T^2}{4\pi^2} a_0 \tag{43}$$

The period of the pitching being about 6 sec, and the amplitude of the acceleration being 0.15 g, we get $u_0 = 135$ cm i. e the distance between the extreme levels of the pulley was 270 cm. The upper end of the cable rising and sinking periodically by this amount, we have to compute the resulting variations of the tension. Using the same denotations as when dealing with the elastic vibrations of the cable (p. 59), we have

$$u_{x=0} = u_0 \sin \frac{2\pi t}{T} \tag{44}$$

If the cable is not very long, it can be treated as a rigid body, in which case the periodical component S of the tension is determined as

$$S = S_0 \sin \frac{2\pi t}{T} \tag{45}$$

$$S_0 = m a_0 = \frac{4\pi^2}{T^2} m u_0 \tag{46}$$

m denoting the mass of cable and load put together.

If the cable has an appreciable length, the elastic vibrations created by the forced oscillations of the upper end of the cable have to be considered. If the frictional resistance of the water is disregarded, the differential equation of the longitudinal elastic vibrations is

$$\frac{\partial^2 u}{\partial t^2} = \frac{E}{\varrho} \frac{\partial^2 u}{\partial x^2} \tag{5}$$

Treating a cable without a load we have the following limiting conditions:

$$x = 0, \quad u = u_0 \sin \frac{2\pi t}{T} \tag{47 a}$$

$$x = L, \quad S = 0, \text{ i. e. } \frac{\partial u}{\partial x} = 0 \tag{47 b}$$

Taking, as before, $u = \varphi(x)\,\psi(t)$, and

$$\varphi(x) = A_1 e^{i\nu x} + A_2 e^{-i\nu x} \tag{8}$$

$$\psi(t) = B_1 e^{i\nu ct} + B_2 e^{-i\nu ct} \tag{9}$$

the first boundary condition, (47 a), implies

$$\psi(t) = \sin \frac{2\pi t}{T} \tag{48}$$

$$\varphi(x) = A_1 e^{\frac{2\pi x}{cT} i} + A_2 e^{-\frac{2\pi x}{cT} i} \tag{49}$$

Then the second boundary condition, (47 b), demands

$$A_1 e^{\frac{2\pi L i}{cT}} = A_2 e^{-\frac{2\pi L i}{cT}} = A \tag{50}$$

whence

$$u = A \cos \frac{2\pi}{cT}(x - L) \sin \frac{2\pi t}{T} \tag{51}$$

$$A \cos \frac{2\pi L}{cT} = u_0 \tag{52}$$

$$u = u_0 \frac{\cos \frac{2\pi}{cT}(x - L)}{\cos \frac{2\pi L}{cT}} \sin \frac{2\pi t}{T} \tag{53}$$

$$S = Eq \frac{\partial u}{\partial x} =$$

$$= Eq \frac{2\pi}{cT} u_0 \frac{\sin \frac{2\pi}{cT}(L - x)}{\cos \frac{2\pi L}{cT}} \sin \frac{2\pi t}{T} \tag{54}$$

Putting $x = 0$ we get the tension at the top of the cable

$$S_{x=0} = Eq \frac{2\pi}{cT} u_0 \operatorname{tg} \frac{2\pi L}{cT} \sin \frac{2\pi t}{T} \tag{55}$$

and the maximal tension is

$$S_0 = Eq \frac{2\pi}{cT} u_0 \operatorname{tg} \frac{2\pi L}{cT} \tag{56}$$

In the case of a rigid cable E is infinitly great, and (56) degenerates into (46), as $E = \varrho c^2$.

According to (56) the amplitude of the periodic component of the tension should be infinite in case $\frac{2\pi L}{cT} = \frac{\pi}{2}$, i. e. $L = \frac{1}{4} cT$. With $T = 6$ sec, the critical length of the cable that will make the tension infinite should be about 5,000 m (Fig. 30).

The preceding treatment has been based on the assumption that the cable can be compressed longitudinally. As that is not the case, i. e. as the imposed tension at a certain point, when negative, cannot exceed the weight of the cable below the point in question, the amplitude of the periodic tension variations at the top of the cable cannot exceed the total weight of

the cable, even if the frictional resistance of the water is not taken into account. However, as the drag of the cable is very considerable even at a moderate velocity, it has to be considered.

The frictional resistance, F dynes/cm, of the water is determined by the velocity v cm/sec and the diameter ϕ cm of the cable.

$$F = C_l \cdot \phi \, v^2$$

The coefficient C_1 has been found to be $C_1 = 0.037$ (KULLENBERG 1951). When the cable is moving downwards, the velocity of its lower part cannot exceed the value making the drag of the lower portion of the cable equal to the weight in water of the same portion. Hence, the diameter of the lower portion of the cable being 1.2 cm, and its weight in water being 0.47 kg/m, we have $v_{max} = 330$ cm/sec. This velocity at the lower end of the cable cannot make the tension reach a critical value. In fact, even if the lower portion of the cable should be brought to a sudden standstill, the tension would only rise to $vq\sqrt{E\varrho}$ (cf. 24 b), i. e. about 650 kp.

The action of waves and swell on a cable carrying a load

The mass of the load is denoted m; $2\pi : T = \omega$. Other denotations are given on p. 67. For the present we do not consider the drag of cable and load, and the differential equation of the elastic vibrations is therefore unchanged (5). The boundary conditions are

$$x = 0 \; : \; u = u_0 \sin \omega t \qquad (57\,a)$$

$$x = L \; : \; m \frac{\partial^2 u}{\partial t^2} = - S \qquad (57\,b)$$

On account of (5) and (57 a) we have

$$u = \left(\cos \frac{\omega x}{c} + A \sin \frac{\omega x}{c} \right) \cdot u_0 \sin \omega t \qquad (58)$$

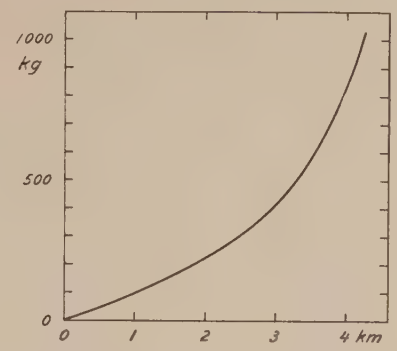

Fig. 30. Diagram showing the amplitude of the tension variations caused in a wire without a load by the periodic vertical movements of the ship due to waves and swell. Period 2π seconds, amplitude 150 cm. The drag of the cable is not considered.

The second boundary condition, (57 b), implies

$$- m \left(\cos \frac{\omega L}{c} + A \sin \frac{\omega L}{c} \right) \cdot u_0 \omega^2 \sin \omega t =$$

$$= - Eq \left(\frac{\partial u}{\partial x} \right)_{x = L} = - Eq \frac{\omega}{c} \left(- \sin \frac{\omega L}{c} + \right.$$

$$\left. + A \cos \frac{\omega L}{c} \right) \cdot u_0 \sin \omega t \qquad (59)$$

whence

$$u = \left(\cos \frac{\omega x}{c} + \frac{1 + \dfrac{Eq}{m \omega c} \operatorname{tg} \dfrac{\omega L}{c}}{\dfrac{Eq}{m \omega c} - \operatorname{tg} \dfrac{\omega L}{c}} \sin \frac{\omega x}{c} \right) \cdot$$

$$\cdot u_0 \sin \omega t \qquad (60)$$

The tension,

$$S = Eq \frac{\partial u}{\partial x},$$

will be

$$S = \frac{Eq \omega u_0}{c} \left(\frac{1 + \dfrac{Eq}{m \omega c} \operatorname{tg} \dfrac{\omega L}{c}}{\dfrac{Eq}{m \omega c} - \operatorname{tg} \dfrac{\omega L}{c}} \cos \frac{\omega x}{c} - \sin \frac{\omega x}{c} \right) \cdot$$

$$\cdot \sin \omega t \qquad (61)$$

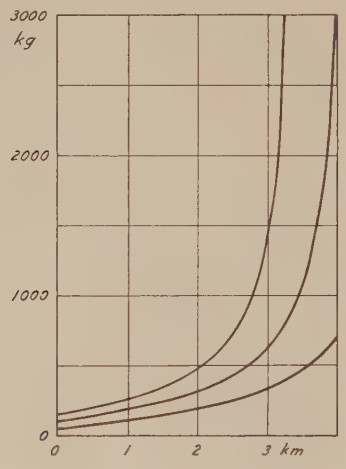

Fig. 31. Diagram showing the amplitude of the tension variations at the top of a 12 mm wire with a load, due to the periodic vertical movements of the ship. Period 2π seconds, amplitude 100 cm. Load 500 kg, 1,000 kg, and 1,500 kg. The drag is not considered.

In the upper end of the cable the tension is

$$S_{x=0} = \frac{Eq\,\omega\,u_0}{c}\,\frac{1+\dfrac{Eq}{m\,\omega\,c}\,\mathrm{tg}\,\dfrac{\omega\,L}{c}}{\dfrac{Eq}{m\,\omega\,c}-\mathrm{tg}\,\dfrac{\omega\,L}{c}}\,\sin\omega\,t \qquad (62)$$

Taking the case of a rigid cable, i. e. 1: $E = 0$, we get

$$S_{x=0} = \omega^2\,u_0\,(m+\varrho\,qL)\cdot\sin\omega\,t \qquad (63)$$

In the case of a rigid cable the tension is determined by the acceleration given to the mass of cable and load together. In the case of an elastic cable the tension is higher, owing to the longitudinal elastic vibrations set up in the cable. This is shown by Fig. 31, giving the amplitude of the tension variations in an elastic cable if the skin friction is not considered according to (62), in some special cases. With a short cable the elastic vibrations do not influence the tension variations very much, but as the length of the cable increases above 2 or 3 km, the tension variations are considerably enlarged by the elastic vibrations. As the cable attains a certain length, making the denominator in (62) disappear, the tension should be infinite; this critical length is determined by the equation

$$\mathrm{tg}\,\frac{\omega\,L}{c} = \frac{Eq}{m\,\omega\,c} \qquad (64)$$

The tension would be fatal to the cable before the critical length, giving resonance, has been reached. *However, thanks to the dissipation of energy due to the drag of cable and load, the amplitude of the tension variations caused by waves and swell will, in practise, remain well below the value given by equation* (62).

We shall now take into account the drag of cable and load. The drag of a body being kv^2 dynes, v cm/sec denoting the velocity of the body, we will compute the loss of energy, W, due to the drag during a complete oscillation, the body swinging according to the equation $u = a\,\sin\omega\,t$. We have

$$W = k\,\omega^3\,a^3\int_{\omega\,t=0}^{2\pi}\left|\cos^3\omega\,t\right|\cdot dt$$

$$W = \frac{8}{3}\,k\,\omega^2\,a^3 \qquad (65)$$

We shall compute the dissipation of energy that would occur, if the cable were swinging

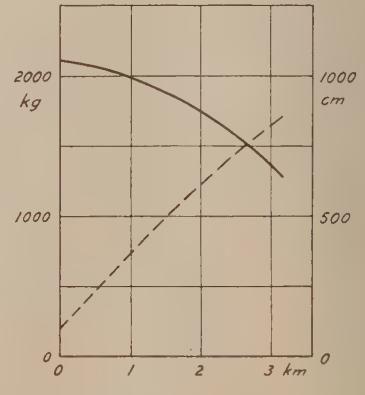

Fig. 32. Diagram showing the amplitude of the tension variations due to waves and swell, as a function of the distance to the ship (fulldrawn line) and the corresponding amplitude of the vertical movements of the wire (dashed line). Diameter 12 mm, length 3,170 m, load 1,500 kg. Period 2π seconds, amplitude of the vertical movements of the ship 100 cm. The drag is not considered.

according to equation (60). By putting $x = L$ we find the equation of the oscillations carried out by the corer suspended from the cable:

$$u_{x=L} = \frac{u_0 \sin \omega t}{\cos \frac{\omega L}{c} - \frac{m \omega c}{Eq} \sin \frac{\omega L}{c}} \qquad (66)$$

Accordingly the loss of energy due to the drag of the corer during a complete oscillation will be

$$W_{\text{corer}} = \frac{8}{3} k \omega^2 \left(\frac{u_0 \sin \omega t}{\cos \frac{\omega L}{c} - \frac{m \omega c}{Eq} \sin \frac{\omega L}{c}} \right)^3 \qquad (67)$$

The drag of a unit length of the cable is $C_l \phi v^2$ dynes, and the drag coefficient has been determined as $C_l = 0.037$. Accordingly, the loss of energy due to the drag of the cable during a complete oscillation will be

$$W_{\text{cable}} = \frac{8}{3} C_l \phi \omega^2 u_0^3 \int \left(\cos \frac{\omega x}{c} + A \sin \frac{\omega x}{c} \right)^3 dx \qquad (68)$$

$$W_{\text{cable}} = \frac{2}{3} C_l \phi \omega c u_0^3 \left[\sin \frac{\omega L}{c} + \right.$$
$$+ \left(A^2 - \frac{1}{3} \right) \sin^3 \frac{\omega L}{c} - A^3 \cos \frac{\omega L}{c} +$$
$$\left. + \frac{1}{3} (A^3 - A) \cos^3 \frac{\omega L}{c} + \frac{2}{3} A^3 + A \right] \qquad (69)$$

For a numerical example we chose $L = 3 \cdot 10^5$ cm, $\phi = 1.2$ cm, $m = 15 \cdot 10^5$ g, $u_0 = 100$ cm, and $T = 2\pi$ sec, i. e. $\omega = 1$. Then we have the loss of energy during a complete oscillation due to the drag of the corer, $W_{\text{corer}} = 22{,}000$ kpm, and the loss of energy due to the drag of the cable, $W_{\text{cable}} = 70{,}000$ kpm, and the total loss of energy during a complete oscillation $W = 92{,}000$ kpm.

The elastic vibrations are maintained by supply of energy at the top of the cable. If there is no loss of energy, there is no supply of energy, stationary conditions being presumed, and accordingly there is no phase difference between the movements of the top of the cable and the tension variations. When there is a dissipation of energy, it has to be made up for by a supply of energy at the top of the cable, which demands a phase difference between the movements of the cable and the tension variations. The phase difference could be found by studying the differential equation of the elastic vibrations containing a term expressing the drag. However, the equation being nonhomogenous, the treatment involves considerable mathematical difficulties, so the practical purpose at hand can be provided for by simpler means.

The supply of energy at the top of the cable during a complete oscillation, W' erg, is the greatest possible, when the aforementioned phase difference between the tension variations and the movements of the ship is a quarter of a period, or 90°. Hence

$$W' < \int_{\omega t = 0}^{2\pi} S_0 \cos \omega t \cdot d (u_0 \sin \omega t) \qquad (70)$$

$$W' < \pi S_0 u_0 \qquad (70\text{ a})$$

In the numerical example treated above we have $u_0 = 100$ cm, $S_0 = 21 \cdot 10^8$ dynes, and accordingly $W' < 66 \cdot 10^{10}$ erg. The simultaneous loss of energy being $W = 92 \cdot 10^{11}$ erg, it is obvious that the elastic vibrations of the cable are very effectively reduced by the drag, which is consequently also the case with the tension variations.

To get an idea of the upper limit of the tension variations caused by waves and swell we will make the simplified assumption that the amplitude of the elastic vibrations of the cable is a linear function of the depth, x cm, below the ship

$$u_x = u_0 + (u_L - u_0) \frac{x}{L} \qquad (71)$$

As demonstrated by Fig. 32 this is approximately the case in the absence of friction, if

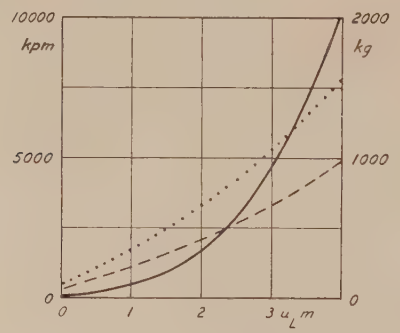

Fig. 33. Computation of the amplitude of the tension variations due to waves and swell when the drag is taken into account. Diameter 12 mm, length 3,000 m, load 1,500 kg. The amplitude of the tension variations at the top of the cable is represented by the dotted line as a function of the amplitude of the vertical movements of the cable at the lower end. The supply of energy at the top of the cable during a complete oscillation is represented by the dashed line. The loss of energy due to friction during a complete oscillation is represented by the full-drawn line. The amplitude u_L corresponding to a steady state is determined at 2.3 m by the point of intersection between fulldrawn line and dashed line. The amplitude of the tension variations corresponding to $u = 2.3$ m is 750 kp

the cable is not very long. The loss of energy due to the drag is determined by (65) and (71).

$$W_{\text{corer}} = \frac{8}{3} k \omega^2 u_L^3 \tag{72}$$

$$W_{\text{cable}} = \frac{8}{3} C_l \Phi \omega^2 \int_0^L u_x^3 \, dx \tag{73}$$

$$W_{\text{cable}} = \frac{2}{3} C_l \Phi \omega^2 L (u_L^4 - u_0^4) : (u_L - u_0) \tag{74}$$

To get an upper limit of the supply of energy at the top of the cable we will compute the tension at the top of the cable as the sum of inertia forces and drag, taking into account that there is a phase difference of 90° between forces and drag. In fact, for every single portion of the cable the drag is a maximum when the velocity has a maximum, whereas the inertia force is zero at that moment. By disregarding the phase differences between inertia forces belonging to different parts of the cable we arrive at too high a tension at the top of the cable, and the same remark applies to the drag. By assuming the phase difference between the variations of the tension at the top of the cable, and the vertical movements of the ship to be 90° we arrive, further, at too high a value of the supply of energy at the top of the cable.

The amplitudes of the inertia forces due to corer and cable are:

$$I_{\text{corer}} = \omega^2 m u_L \tag{75}$$

$$I_{\text{cable}} \leqq \frac{1}{2} \omega^2 \varrho q L (u_L + u_0) \tag{76}$$

The amplitudes of the drag, D, of corer and cable are as follows, disregarding the fact that the drag is not a harmonic function of the time:

$$D_{\text{corer}} = k \omega^2 u_L^2 \tag{77}$$

$$D_{\text{cable}} \leqq C_l \Phi \omega^2 \int_0^L u_x^2 \, dx \tag{78}$$

$$D_{\text{cable}} \leqq \frac{1}{3} C_l \Phi \omega^2 (u_L^2 + u_L u_0 + u_0^2) \cdot L \tag{78 a}$$

The amplitude of the variations of the tension at the top of the cable being S_0, we have

$$S_0^2 = (I_{\text{corer}} + I_{\text{cable}})^2 + (D_{\text{corer}} + D_{\text{cable}})^2 \tag{79}$$

Using eq. (70 a), (71), (74), and (79) the supply of energy at the top of the cable during a complete oscillation, and the simultaneous loss of energy due to the drag of corer and cable have been computed in two instances, viz. the length of the cable being 3,000 m resp. 6,000 m, the diameter bing 12 and 14 mm, and the weight of the corer being 1,500 kg. The diameter 14 mm, in the last mentioned case, has been chosen as being the medium diameter of the first 6,000 m of the cable actually used on board the Albatross. The supply of energy and the loss of energy have

been represented as functions of the amplitude of the vibrations of the cable at the lower end. Stationary conditions demanding equality between supply of energy and loss of energy the point of intersection between the two curves will give the actual amplitude of the vibrations at the lower end of the cable or, rather, an upper limit of the amplitude. The amplitude of the variations of the tension at the top of the cable being represented in the same diagrams, we find the upper limit of the tension variations due to waves and swell.

In the case of a 3,000 m cable with a diameter of 12 mm and carrying a load of 1,500 kg, the variations of the tension due to waves and swell will not exceed $\pm$ 800 kp, if the vertical displacement of the ship is $\pm$ 100 cm and the period about 6 sec. (fig. 33).

In the case of a 6,000 m cable with a diameter of 14 mm and carrying a load of 1,500 kg, the corresponding variations of the tension do not exceed $\pm$ 1,300 kp. (fig. 34).

The two instances just mentioned make it obvious that the dissipation of energy due to the drag of cable and corer prevents the variations of the tension due to the vertical movements of the ship, caused by waves and swell, to attain a critical intensity. Whereas in the absence of friction even moderate periodical displacements of the top of the cable should suffice to break the cable because of the resonance attained when an adequate length has been unreeled, the frictional resistance of the water prevents resonance vibrations to be developed.

In the two cases just treated the amplitude of the vibrations at the lower end of the cable is found to be slightly above 200 cm, when the corresponding amplitude at the top of the cable is 100 cm. Accordingly the vibrations are more intense at the lower end of the cable than on board the ship. This is indirectly verified by the observation that the variations of the tension in the cable during a coring operation are considerably smaller when the corer is immersed in the sediment, thus stopping the vibrations of the lower end of the cable, than otherwise.

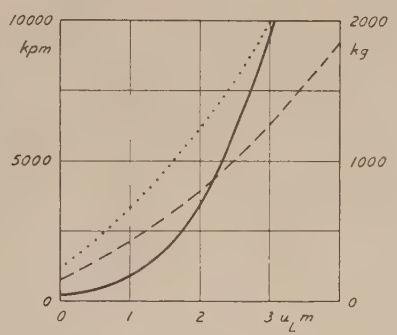

Fig. 34. Computation of the amplitude of the tension variations due to waves and swell when the drag is taken into account. Diameter 14 mm, length 6,000 m, load 1,500 kg. Cf Fig. 33. The amplitude u_L corresponding to a steady state is determined at 2.1 m by the point of intersection between fulldrawn line and dashed line. The corresponding amplitude of the tension variations is 1,300 kp.

Accidental release of the corer

If the corer is accidentally released before it has reached the bottom of the sea, it will fall 10—20 m, according to its length, before it is checked by the cable. In the meanwhile the cable, relieved of the weight of the corer, will contract, and the tension imposed by the corer will disappear. The elastic longitudinal vibrations started in the cable at the moment of accidental release are damped by the drag of the cable, and we may disregard what might be left of the vibrations at the end of the free fall of the corer.

The velocity of the corer at the end of the free fall being v cm/sec, and the unreeling speed being v_1 cm/sec, the cable will be lengthened at the rate of $(v - v_1)$ cm/sec immediately after the top of the corer has reached the piston, which marks the end of the free fall. At the same time an elastic wave will run upwards in the cable with the velocity $c = \sqrt{E : \varrho}$ and if the drag of the cable is disregarded the deformation of the cable is evenly distributed over the part covered by the elastic wave. There-

fore, the tension raised at the lower end of the cable when the corer is caught by the cable, amounts to $Eq \cdot (v - v_1) : c = (v - v_1)\, q \sqrt{E \varrho}$. This is a moderate tension and does not involve any immediate risk for the cable. However, if the cable is short, the elastic wave will be reflected several times at both ends of the cable before the velocity of the corer has been brought down to the unreeling speed, and as the tension will rise at each reflection it may reach a critical value. Even if the cable has a great length, the tension at the lower end will increase, because the part of the cable covered by the elastic wave will experience a drag, part of which will contribute to the tension at the lower end of the cable, whereas the tension near the wave front will be diminished by the action of the drag.

We will estimate the maximal tension in a special case, viz. the weight of the corer being 1,500 kg and the unreeling speed being 170 cm/sec (100 m/min). In computing the maximal velocity of the corer we take into account the resistance raised by the water contained in the tube, when forced by the piston to leave the tube. The sectional area of the water exit being about one third of that of the lining tubes, the resistance referred to will increase the drag coefficient of the corer by about 100 g/cm, or from 1,500 to 1,600. Accordingly the asymptotic velocity of the corer is about 900 cm/sec. In the moment of impact the tension will be $(v - v_1)\, q \sqrt{E \varrho} = 1{,}540 \cdot 10^6$ dynes, which is about the same tension as the one existing before the accidental release. If the cable is short the tension will rise discontinually each time the elastic wave is reflected at the lower end, and in the intervals the tension will change continually because of the changing velocity of the corer and the changing drag of the cable. To simplify matters we will treat the cable as if it has no weight, the essential consequence of the assumption being that the tension is a function of time only. The unreeling speed being v_1, and u being the distance travelled by the corer after the moment of impact, the elastic lengthening of the cable will be $u - v_1 t$ and the tension $S = Eq \cdot (u - v_1 t) : L$. Putting $g\,(1 - 1/\varrho) = g'$, and disregarding the drag we have:

$$m \frac{d^2 u}{d t^2} = mg' + \frac{Eq}{L} v_1 t - \frac{Eq}{L} u \qquad (80)$$

$$u = u_0 \sin\left(\sqrt{\frac{Eq}{m L}}\, t - \alpha\right) + v_1 t + \frac{mg' L}{Eq} \qquad (81)$$

Applying the boundary conditions $u = 0$, and $du/dt = v$ at $t = 0$ we arrive at a positive α and a maximal velocity greater than v. This is a consequence of our disregarding the drag. As a matter of fact, the velocity of the corer does not rise above v but starts decreasing as soon as the free fall after the accidental release has reached its end. It is true that the drag coefficient of the corer will be reduced as soon as the piston has reached the top of the tube but this is compensated by the initial tension in the cable created by the pressure exercised on the piston by the water in the tube. Therefore we prefer to eliminate α from the expression (81) by putting $t = 0$ at the moment when $u = mg' L : Eq$, making $S = mg'$, which is the normal tension in the cable (disregarding the insignificant drag corresponding to the unreeling speed) before the accidental release as well as after the vibrations caused by the accidental release have been eliminated by friction. In determining u_0 we disregard the fact that du/dt is slightly smaller than v at $t = 0$. Accordingly we get

$$u = (v - v_1) \sqrt{\frac{m L}{Eq}} \sin \sqrt{\frac{Eq}{m L}} \cdot t + v_1 t + \frac{mg' L}{Eq} \qquad (82)$$

$$S_{\max} = mg' + (v - v_1) \sqrt{\frac{Eq\, m}{L}} \qquad (83)$$

Putting $m = 15 \cdot 10^5$ g, $g' = 900$ cm/sec², $Eq = 8 \cdot 10^{11}$ dynes, $v = 900$ cm/sec, and $v_1 = 170$ cm/sec, we get

$$S_{\max} = 1350 \cdot 10^6 + 80 \cdot 10^{10} : \sqrt{L}$$

The length of the cable being $L = 10^5$ cm, i. e. 1,000 m, we get $S_{\max} = 3{,}880 \cdot 10^6$ dynes, i. e. 3,880 kp. The breaking strain of the cable being about 10,500 kp the jerk does not endanger the cable. Even if the length of cable paid out in the moment of accidental release is only $25 \cdot 10^3$ cm, i. e. 250 m, the cable has a fair chance to stand the strain without being damaged, as the maximal tension should be $S_{\max} = 6{,}400 \cdot 10^6$ dynes i. e. 6,400 kp. In fact, thanks to the influence of the drag the tension should be slightly smaller than stated above.

The above considerations lead to the conclusion that no accumulator is needed to smooth sudden variations of the tension. As reported in a previous paper (KULLENBERG 1947) a corer weighing 720 kg was accidentally released in 1946, 1,500 m of the cable having been paid out on that occasion. No damage was caused to the cable. During the cruise of the Albatross the corer was accidentally released several times, especially when the cable had been used at a trawling prior to the coring operation. In no case did the cable suffer any perceivable damage by the accidents. Thus, the decision not to use an accumulator has been justified by events.

Tension arising in the portion of the cable passing over the pulleys of the winch

The winch is acting on the cable by two pulleys with a diameter of 800 mm, fitted with a number of grooves for the cable to run in. As a rule five turns of the cable were laid over the pulleys and the part of the cable on the pulleys had a length of about 35 m. When a cable with uniform width is hauled in by the pulleys, no complications arise, unless one or two of the grooves have been worn more than the rest, which case we will consider later. However, when a tapered rope is hauled in, complications do arise at the moment one of the junctions arrive, where the diameter of the cable is reduced to a lower value. The thicker part of the cable is running in at a certain speed, and the thinner portion of the cable follows at a slightly lower speed. In fact, if the difference between the diameters of the two parts of the cable is $\Delta \phi$, the thinner part will lag behind as much as $\pi \Delta \phi$ with each revolution of the pulleys. In the cable from *Wright's Ropes CO, LTD*, $\Delta \phi = 4$ mm, and the length of the junction is about 5 m. The junction being lengthened about 60 mm before it has passed the pulleys, the tension is increased by about 9,000 kp when the junction between the 16 mm portion and the 12 mm portion is passing the pulleys, and by about 17,000 kp, when the junction between the 20 mm part and the 16 mm part is passing over the pulleys. Though the cable will be able to escape breakage a few times by eliminating the lengthening of the junction in jerks, the strain will injure the cable severely and ultimately break it. In fact, though the tension raised in the same way in the cable from the *Swedish Wire Rope CO, LTD; Hellefors*, was smaller because the junctions were longer and the change in diameter smaller, the strain did break that cable before I understood the cause of what happened.

The remedy was found in lubricating the critical portions of the cable thoroughly. Further, it was necessary to make the tension in the cable very small between the pulleys and the drum, which it was possible to do without slackening the cable, thanks to the accumulator introduced at that place for other reasons. The winch was driven at a very low speed as a critical part of the cable passed over the pulleys. The heavy lubrication and the small tension in the inner end of the cable allowed the cable to slide on the pulleys, thus

Fig. 35. The piston corer at the starboard rail of the »Albatross».

eliminating the stretching of the cable and the ensuing extra tension. The sliding of the cable was facilitated, when necessary, by making the cable taut between the two pulleys by means of a wooden lever and then releasing it suddenly, which operation was continually repeated until the critical part of the cable had left the pulleys.

With these precautions, no further damage was caused by the circumstances here discussed. In fact, one of the two long cables from *Wright's Ropes, Ltd, Birmingham*, was used until the end of the cruise without any perceivable damage occuring to it, and the other cable was kept unused as a reserve.

When the cable is being paid out, no precautions need be taken when there is a junction passing the pulleys, as the effect is then reversed and makes the tension in the junction lower than in the adjacent parts of the cable.

When the winch had been used a few months there were signs that the two grooves occupied by the cable immediately before it left the pulleys to proceed into the sea had been slightly worn. This was obviously caused by the higher tension of the cable in the outermost grooves. As a consequence the speed of the cable was lower during the hauling in these two grooves than in the other grooves, which caused an extra tension in a similar way as has just been described. This was indicated by a frequent cracking as the wire slipped on the pulleys owing to the increased tension. To overcome this inconvenience the position of the cable was changed now and then so as to wear all the grooves equally. Further, similar precautions were taken as previously described, the cable was kept lubricated and the tension between the pulleys and the drum was not allowed to rise very much.

Core Sampling during the Swedish Deep-Sea Expedition

Arrangements on board to facilitate the core sampling

To make the operation of the long and heavy piston corer possible, certain arrangements had to be made on board. Along the starboard rail a bridge was built between poop deck and bridge deck in order to allow sufficient space at the rail for a corer with a 20 m long coring tube, the total length of the corer being then slightly less than 23 m. On the rail, semicircu-

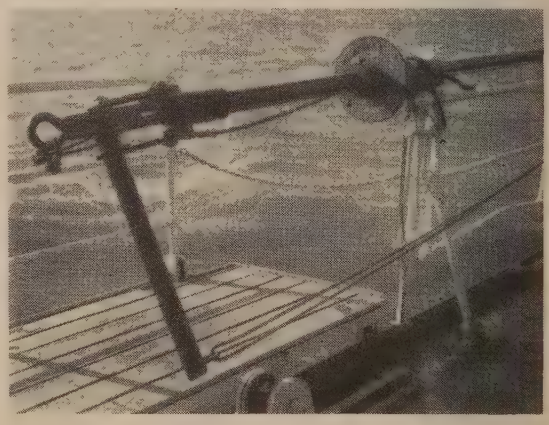

Fig. 36. The top of the corer at the starboard rail, and the balcony on the bridge deck.

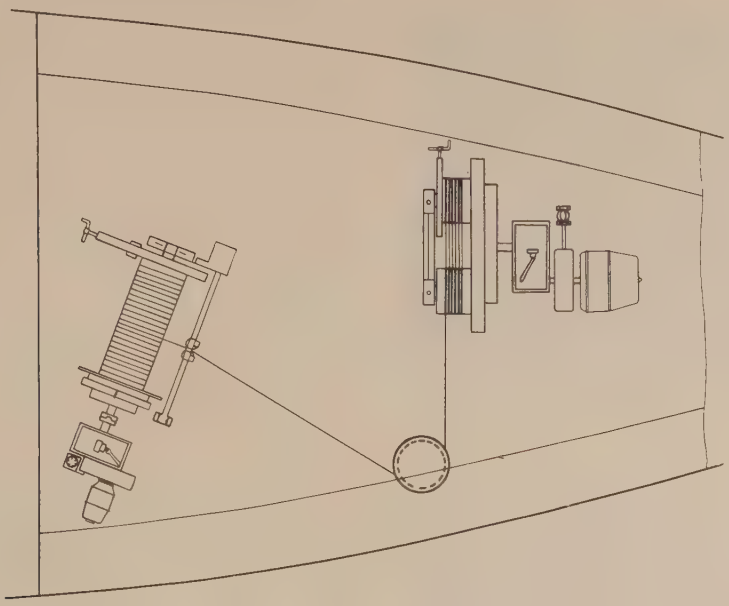

Fig. 37. Plan of hold No. 1.

lar holders for the tube were mounted at intervals of 4 m, allowing the coring tube to be kept lying on the rail, between the coring stations. This is a very convenient position for the corer, being close to the water and outside the stays which would otherwise present a serious obstruction, when the corer is to be put into the sea. On the bridge deck, near the foreside of hatch No 2, an outboard balcony, 60×120 cm, was erected at the starboard side. When the corer was resting on the holders on the rail, the upper end of the coring tube was situated at the sternward end of the balcony.

On the main deck, beside hatch No. 1, a davit was erected at the starboard rail, carrying a pulley with a diameter of 800 mm, by which the steel rope carrying the corer was to be conducted into the sea. On the sternward side of the davit, slightly below the rail, a platform was erected from which the corer could be handled comfortably. At one end the platform was supported by a tube, 80 mm in diameter, serving to support the drive-weights kept ready for the corer.

For the handling of the corer three electric deck-winches and three booms could be used, one on the forecastle deck, and two on the bridge deck.

The trawl winch used to lower the corer to the bottom of the sea was stationed in hold No. 1. The position of the winch and the track of the cable are seen in Figs. 37 and 38. As shown in Fig. 37, which is a plan of hold No. 1, the cable-drum is set up close to the sternward bulkhead, its axis forming an angle of 20° with the bulkhead. The main part of the winch was set up below the hatch, at the port side of the hold, the two pulleys with their axis parallel to the direction of the ship. The axis of the drum forming an angle of 110° to those of the pulleys, the cable had to be conducted from the cable-drum to the pulleys by a horizontal sheave set up below the hatch, at the starboard side of the hold. As set out in the description of the trawl winch the tensile force was transferred to the cable by the two pulleys of the winch, whereas the object of the cable drum was to store the cable in a state of low tension. It could not be avoided that, occasionally, the cable went slack between the pulleys and the drum, the risk for such an accident being

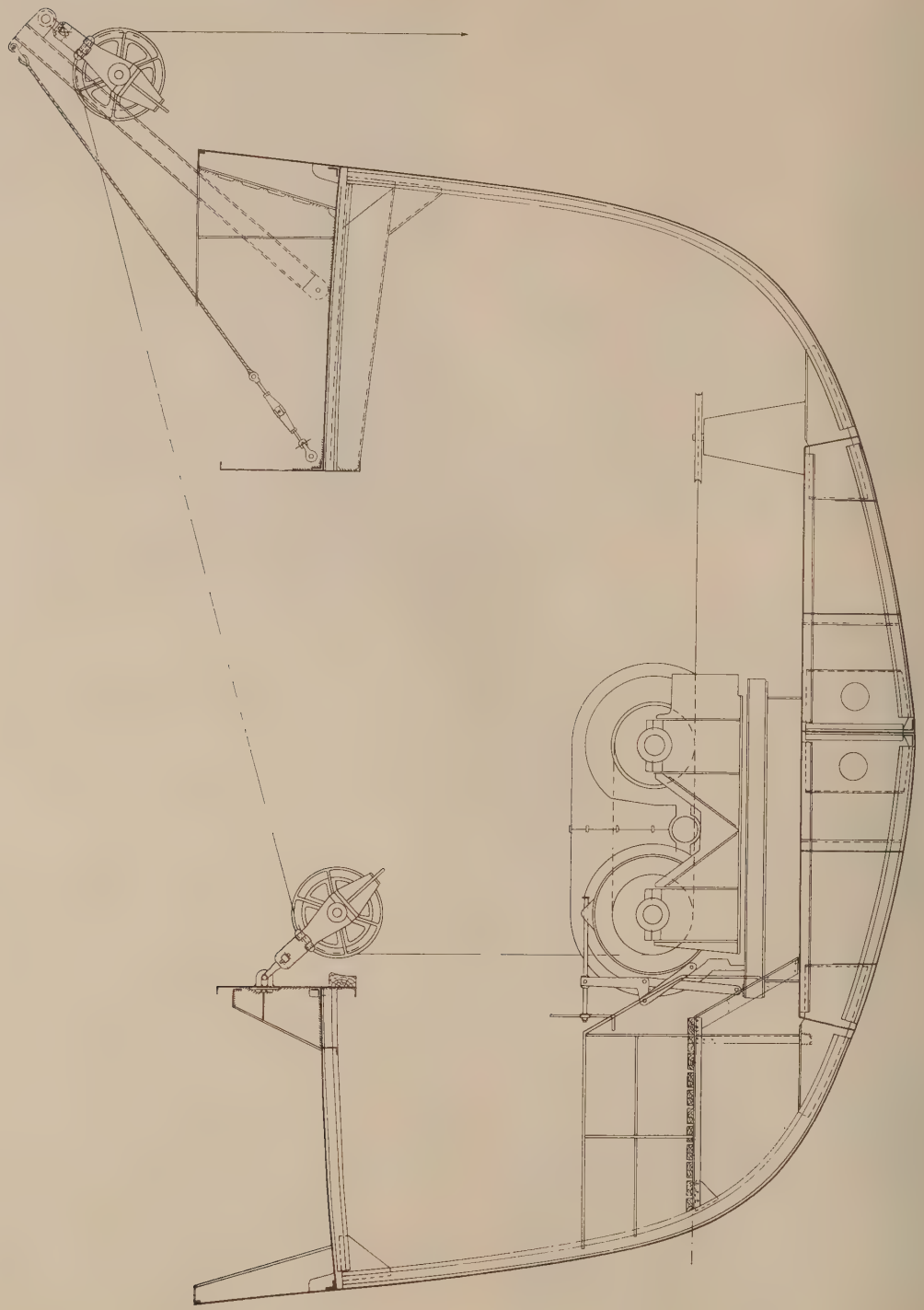

Fig. 38. Schematic view of the winch in hold No. 1, and the davit on the main deck, and the track of the cable.

particularly great during the hoisting. As the cable, if turning slack anywhere but at the free end would inevitably kink and get spoiled the slack had to be absorbed. To that end a mechanical accumulator was prepared between the cable-drum and the horizontal sheave as shown by Fig. 41. Halfway between the drum and the sheave the cable was pulled upwards by a small block suspended from a wire passing over two other blocks at the top of the hold, and carrying a load of about 50 kg at its other end, running in a vertical tube. The accumulator being able to take home 4 m length of the cable, the operator of the winch was given time to take the necessary measures, should the accumulator block indicate impending slacknes by allowing itself to be pulled upwards. The accumulator serving at the same time as a dynamometer, it was possible to prevent the tension in the cable between the pulleys and the cable drum from getting unnecessarily high.

At the top of the hold, at the port side of the hatch, a sheave was set up serving to conduct the cable from the winch to the davit on the main deck. All sheaves and pulleys, including the one in the davit, had a diameter of 800 mm and were made of steel casting in order not to be much worn by the cable which is made of very hard steel.

A dynamometer was mounted halfway between the sheave in the davit and the one in the hatch (Fig. 42). It consisted of a steel casting block with a diameter of 30 cm, which pulled the cable downwards, being fastened to an eye in the hatch by means of a stretching screw. An oil cylinder with a piston (a motor car wheel brake cylinder) was inserted between the block and the stretching screw in such a way that the piston was brought to exert a pressure on the oil proportionate to the tension in the rope. The oil pressure was measured by a gauge attached to the cylinder, and the tension in the cable was found by multiplying the readings by a reducing factor.

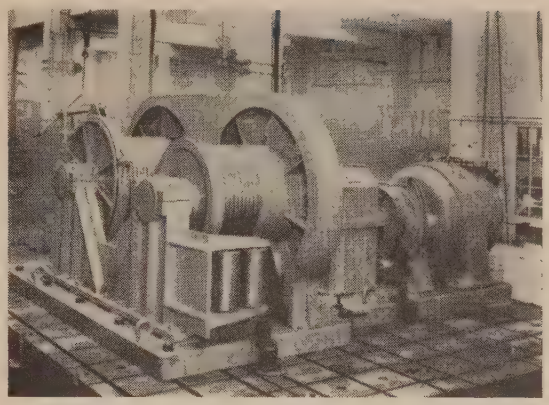

Fig. 39. Photo of the main winch.

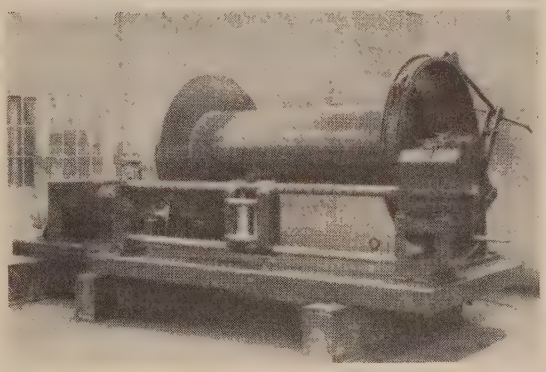

Fig. 40. Photo of the cable drum belonging to the main winch.

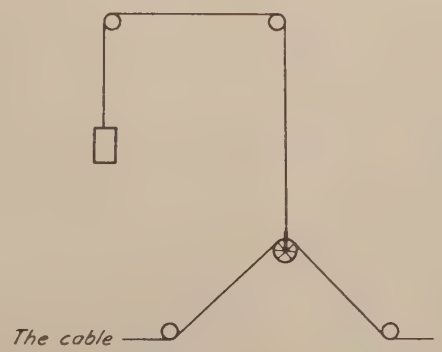

Fig. 41. The accumulator between the main winch and the cable drum (schematic).

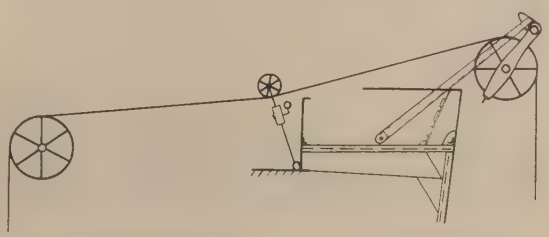

Fig. 42. Schematic view of the dynamometer.

Fig. 43. The dynamometer consisting of oil cylinder and pressure gauge.

In order to diminish the very considerable wear of the dynamometer block, the dynamometer was generally used only immediately before the corer was expected to reach the bottom, during the final 200 m, and while the corer was being pulled out of the bottom. To make it easy to connect, or disconnect, the dynamometer, a balcony was erected at the top of the hold, immediately below the dynamometer. As it is essential to be able to stop the winch very quickly as soon as the dynamometer has indicated the release of the corer, a switch was set up near the dynamometer, making it possible for the man watching the tension in the cable to stop the winch at the right moment without having to communicate with the winch operator since it was possible to stop the winch abruptly at full speed.

The course of a deep-sea coring

To get the corer ready the lining tubes are introduced into the coring tube through its lower end, every tube being joined to the foregoing one with a collar as it is being pushed into the steel tube. The last lining tube is fitted with a frame at its lower end. Every lining section has a number punched on it at one end, and in order not to confuse the upper and lower ends of the core sections, each lining section is introduced into the steel tube with its number at its lower end. Then the piston rope is pushed through the tubing, and the piston is introduced into the mouth-piece, which is then screwed into the coring tube until stopped by the lining tubes. The lining tubes are then fixed into position, by the stop ring (item 13) at one end and by the mouth-piece at the other end. The piston rope being run through the weight tube (item 8), the weight stand is attached to the top of the coring tube. Finally, the release mechanism is brought into position and the piston rope is attached to the eye of the core sampler. The suspending link (item 4) is attached to the short arm of the lever, and the safety link (item 6) is attached to the long one.

Three wrought iron clamps (Fig. 44) are laid round the tube, one at each end and one midway between them. The clamps are fixed in these positions, the lowest one by means of a funnelshaped catch put over the mouth-piece and a rope connecting it with the other clamps. The clamp at the other end of the tube, one or two metres below the top, is attached there with a 6 mm wire rope. Then a 10 mm rope is fastened to each clamp, the other end of the three 10 mm ropes being kept together by a schackle, fastened in its turn to a rope intended to swing the tube over board. The counterweight bar (item 30)

Fig. 44. The funnel shaped catch for the lower end of the tubing, and one of the clamps serving to lower the corer into the sea.

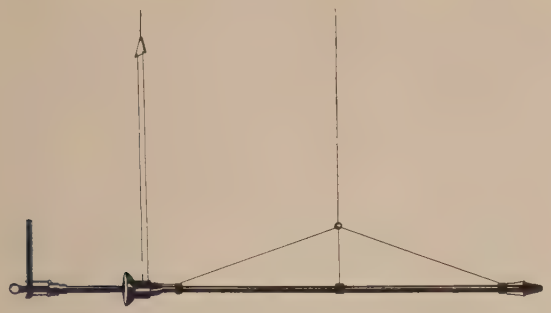

Fig. 45. Schematic drawing of the corer hanging in a horizontal position.

being situated at this stage at the top of the tube, an auxiliary rope is shackled to the upper end of the counterweight rope, making it possible to hoist the top of the corer in the counterweight bar.

Now the core sampler is ready to be hung out into the sea, which is performed in the following way. The ship having stopped after having been brought to head the sea, the corer is lifted above the rail in a horizontal position, hanging there from two ropes, namely the counterweight rope and the rope connected to the three clamps (Fig. 45). The corer is then brought outside the rail and lowered into the water, the lower end being kept one or two metres below the top until the tube has been filled with water. Then the corer is brought into a vertical position by paying out the rope attached to the clamps until it is slack and by hauling in the counterweight rope until the top of the corer hangs conveniently high above the bridge deck. The corer is now hanging in the yardarm of the mainmast close to the balcony on the starboard side of the bridge deck, and it is being made fast to this one in order to prevent it from swinging while the clamps are being removed. Then a wire rope from the yardarm of the foremast is shackled to the upper end of the counterweight rope, the corer having first been lowered to a convenient level. By hoisting the foremast wire and paying out the mainmast wire until it is slack, the corer is brought into a new position outside the platform on the sternward side of the davit close to hatch number one, on the maindeck. The mainmast wire having been removed, and the corer having been made fast again, to prevent it from swinging, an adequate number of the semicircular drive weights are put on the weight stand. Then the long cable leaving the ship over the pulley beside the platform, is attached to the eye of the corer and hauled tight. At the same time the counterweight is lowered to its position near the lower end of the tube, and the counterweight rope is attached to the long arm of the lever. Now the corer is hanging from the long cable, the release mechanism being situated close to the rail. The lowering of the cable begins as soon as the safety link has been removed, the sign to lower being given to the winchman by showing him the safety link. If there is any appreciable swell, the ship should head the sea during the operations in order to keep

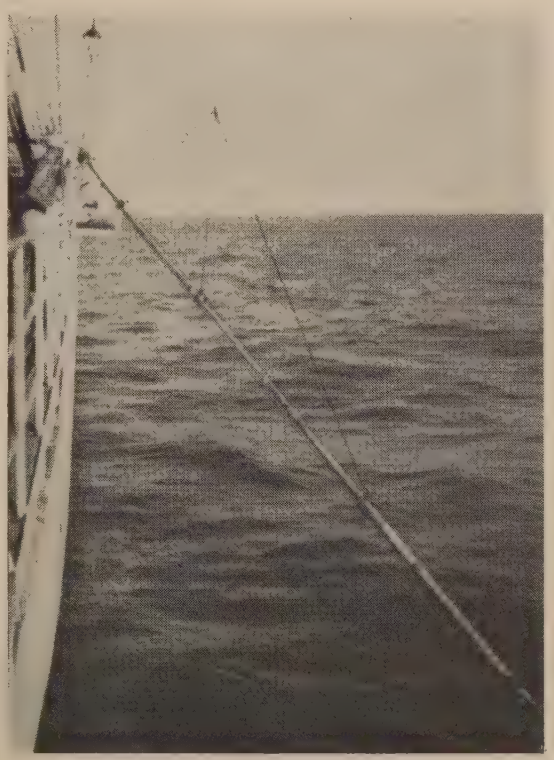

Fig. 46. The piston corer is lowered into the water.

the rolling as small as possible. During the first stage of the lowering it is essential to prevent the lever from touching the ship.

The lowering was carried out at a velocity of 100 m/min until, according to the meter wheel and the echo sounder, there remained about 200 m to the bottom. Then the lowering was stopped and the winch was changed from single transmission to double transmission whereby the maximum velocity is halved, and the maximum force doubled. At the same time the dynamometer was put into action, and before the lowering was started again the tension in the cable was read as accurately as the variations caused by the swell allowed, which were sometimes considerable. After the lowering had been started again, the dynamometer was kept under close observation in order to find out exactly when the corer reached the bottom, which was marked by the tension making a sudden leap to a smaller value. As soon as this characteristic jerk of the dynamometer had been observed, the winch was stopped by pressing a button stationed close to the dynamometer. When running at full speed the winch paid out about 30 cm wire after the button had been pressed. Owing to the tension variations caused by the swell it was sometimes difficult to tell with certainty whether the corer had reached the bottom, or not, especially since the dynamometer was exposed to very intense vibrations as long as the wire was running, because the wire was rather rough. Therefore the dynamometer had to be read carefully immediately after the lowering had been stopped. Sometimes the dynamometer made a jerk towards higher tension about four seconds after the lowering had been stopped — this jerk was caused by the piston catch (item 16) striking the piston and it proved that the corer had reached the bottom and that it had penetrated to its full length into the bottom. A further proof that the corer had reached the bottom was furnished by reading the dynamometer after the second jerk; if then the tension was lower than the one read about 200 m higher up, the corer had certainly reached the bottom. This control could always be observed even if the corer had not been loaded sufficiently to penetrate into the bottom to its whole length. The hoisting of the corer should be started as soon as possible in order to allow the corer no time to be stick into the bottom. During the hoisting the dynamometer should be observed closely. As a rule the tension will increase appreciably during the hoisting, if the corer has reached the bottom, owing to the frictional resistance due to the sediment, even though this resistance diminished considerably after a mouth-piece with a greater width than the tube was introduced. In most cases the resistance is too small to cause any inconvenience, and then the corer can be pulled out of the bottom in one stroke. Occasionally the resistance may be very great, and then the tension in the rope might rise so as to endanger the rope, if the hoisting is to rapid. The tension should not be allowed to surpass a certain fraction of the breaking strength of the rope; this limit being reached, the hoisting must be stopped for a while. Then the cable will shorten slowly, pulling the corer upwards, whereupon the tension will decrease correspondingly. By taking home the cable little by little the tension is kept up without surpassing the limit. Very soon the tension will jump down to a lower value, indicating that the corer has become detached from the firm grip of the sediment. By the suddenness of the change it can be inferred that once the corer has come loose it is being pulled out of the bottom very quickly by the tightly stretched steel rope, which in fact, may have been lengthened several metres by the extra tension caused by the resistance of the sediment. If 6,000 m of cable has been paid out, an extra tension of 1,500 kg will lengthen the cable 10 m. One may, therefore, take home 10 m,

or more, of the cable without the corer being moved, whereas, on the other hand, once the corer has come loose it will move as many metres, and very rapidly, without any more rope being hauled in.

During the first stage of the hoisting the winch must be run with double transmission owing to the weight of the cable. This will reduce the maximum velocity to 50 m/min, and with very much cable paid out the hoisting velocity must be reduced even more. With 3,000 m wire still paid out it is possible to change over the winch to single transmission, and then the velocity can be increased to 100 m/min. In order to be able to keep a high velocity as long as possible, a mark painted on the rope some 50 m above its lower end, warns the operator of the winch that the corer is near the surface.

The hoisting has to be stopped when the release mechansim has reached the pulley in the davit. Then the bulk of the corer is hanging several metres deeper, at a depth equal to the length of the piston wire, as the corer is hanging by the piston. An auxiliary rope running over a pulley on the foremast boom is shackled to the counterweight rope, which is then unfastened from the lever of the release mechanism. The auxiliary rope is hauled in until the corer is hanging from the counterweight rope, the counterweight bar supporting the drive weights. Then the piston rope is detached from the release mechansim, which is left hanging by the main cable close to the pulley in the davit, to be taken on board later, when the more urgent work is finished. After the corer has been lifted to a convenient height, the drive weights are removed. Then an auxiliary rope from the mainmast boom is shackled to the counterweight triangle, and by hauling in the mainmast rope and paying out the foremast rope the corer is being brought sternwards until it has reached the balcony on the bridge deck. The corer is lifted to a convenient height,

Fig. 47. The hauling is finished and a short gravity corer is being taken on board after having served as a pilot weight. Photo Bruneau.

the counterweight rope is unfastened from the triangle and is left connected to the foremast wire until the next coring operation. Now the clamps are laid around the coring tube and are lowered down to their stations. The rope being adequately marked, the clamps are lowered until the undermost one has come down to the mouth-piece. Then they are hauled up a few inches, whereby the funnel-

Fig. 48. The drive weights are removed. Photo Bruneau.

Fig. 49. One of the clamps is being attached to the corer as a preparation to take the corer on board. Photo Bruneau.

shaped catch will be stopped by the mouth-piece. The uppermost clamp is fastened to the top of the tube, and thus the three clamps are fixed in their places.

Now the rope attached to the clamps, which is running over a pulley in the cross mast boom, is hauled in until the corer has been brought into a horizontal position immediately above the rail. It is laid down in the holders on the rail, after which the ship can proceed on its course again. The time spent on the coring operation has to be reckoned from the moment the ship stopped till the moment it can start again, the work carried out when the ship is running involving no loss of time.

Fig. 50. The lower end of the core contains globigerina ooze. Photo Bruneau.

Before the lining tubes can be extracted, the weight stand, the piston, the mouth-piece, and the stop ring at the top of the coupling have to be removed. Then the lining tubes are taken out through the lower end of the coring tube, being pushed from the top end by means of slender iron tubes successively screwed together. The collars keeping adjacent sections of the lining tubes together are carefully put aside, and then the core is cut off cheese-wise with a thin wire inserted between the two lining tubes. The number of each lining tube has to be checked as it is taken out. The lining tubes are covered with brass lids, both ends of the core sections having first been protected by circular celluloid plates. To avoid confusion of the lower and upper ends of the core sections the celluloid plate at the lower end had a black mark on it.

From the moment the ship had been stopped at a coring station till the moment the corer was ready to be lowered, hanging in the davit on the main deck, being charged with the drive weights and relieved of the safety link, not more than 15 minutes used to elapse. The same time was needed to take the corer on board after it had been hauled up from the bottom to the ship. Adding the time required for lowering, hoisting, and applying the dynamometer, we find the time necessary to take a core at a depth of 3,000 m to be $1^h\,40^m$, at 4,000 m $2^h\,10^m$, at 5,000 m $2^h\,50^m$, and at 6,000 m $3^h\,50^m$.

The treatment of the cores on board

As soon as possible the core is extracted from the lining tubes and stowed in a room where the temperature is kept at 4° C—8° C. To

extract the cores, a »core extractor» was put up in the »sediment lab», consisting of a piston at the end of a long rod and a device by which a lining tube section could be pulled in the direction of its axis against the piston, which was kept stationary (Fig. 54). The piston, inserted into the lining tube at one end, after the tube has been fitted with a tightly fitting extension tube, will push out the core. As the tube should be moved uniformly in order not to damage the core, and as the resistance of

Fig. 51. The top of the corer is being unscrewed. Photo Bruneau.

the core is sometimes very great, the tube is pulled by means of a wire fastened to a drum-wheel fitted with a handle. One end of the piston rod is fastened below the drum-wheel in such a way as to be easily removed. As the piston does not move, the sample will lie still and only the tube will be moving. The sample is collected on a plate with a shallow groove in it, the plate lying immediately below the tube before the pulling is started. The plate is covered with a cellophane sheet, 20×78 cm. The cellophane used for the purpose is a cellulose acetate, which is able to stand moisture very well for a long time.

The sample is exposed to a rapid examination, the length being checked, the water content being estimated, and the general character of the sediment established. The colour is stated with reference to the OSWALD scale, and in case the core is conspicuously stratified, the strata are indicated briefly. As the whole examination is carried out without cutting the core, and only after having scraped its surface very carefully, the description made on board cannot be expected to be very accurate, but nevertheless it is helpful at the planning of the thorough investigation to be carried out after the end of the expedition.

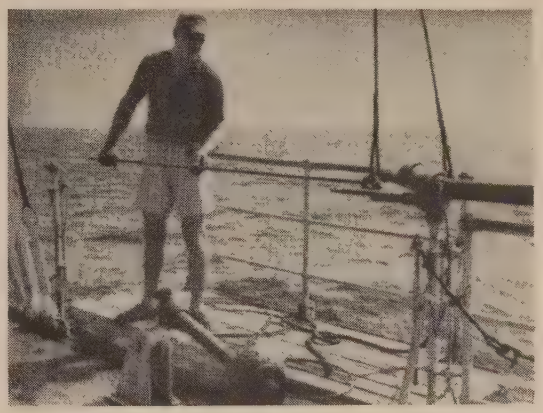

Fig. 52. The lining containing the sample is being pushed out of the steel tubing. Photo Bruneau.

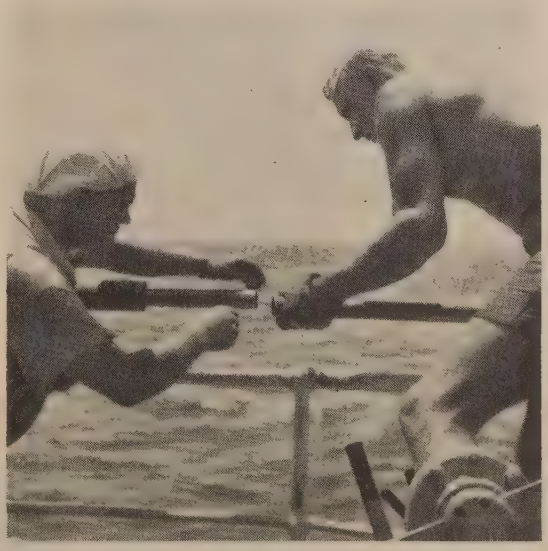

Fig. 53. The lining tube sections are extracted from the steel tubing at the lower end, and the core is cut with a thin wire between adjacent sections. Photo Bruneau.

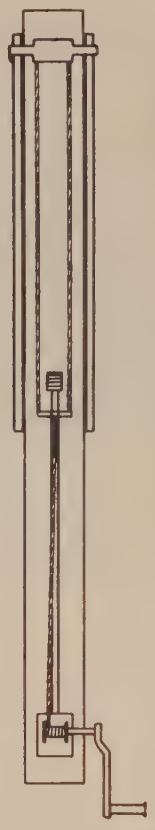

Fig. 54. The core extractor.

The cursory examination finished, the core section was wrapped in the cellophane sheet, and a thick circular plate of the same material was applied to each end of the sample. The plate at the lower end of the sample was given a black mark. The cellophane sheet was sealed up with a solution of cellophane in acetone so as to make the parcel as tight as possible, and to the same end the parcel was rolled into one more cellophane sheet which, like the inner one, was sealed along the cylindrical surface and at both ends. Then the parcel was placed into an aluminium tube, 50 mm wide and with a wall thickness of 1 mm, the interior having been covered with a thin sheet of molten paraffine wax immediately before. Molten paraffine was, at a temperature of about 55° C, poured into the aluminium tube little by little, until the sample was covered completely at both ends. The aluminium tube was closed at both ends by paraffined cork stoppers, and the stoppers were sealed with a quick-drying varnish, blue colour being used for the lower end, red for the upper end. A number painted at the lower end of each aluminium tube gives the number of the core, and the number of the core section starting from the top of the core. For instance, with core No. 117, the core section at the top of the core was marked 11701, the following sections (most of them 70 cm long each) being marked 11702, 11703, and so on. Finally the aluminium tubes were stowed in cases and placed in the store room made ready for the sediment samples, where the temperature was kept low, between 4° C and 8 °C.

The careful stowing of the samples was meant to preserve them as unchanged as possible, until they could be subjected to examination on shore. It was hoped that no water would escape through the cellophane sheets and through the paraffine wax surrounding the sample. The paraffine wax filling was used in order to support the sample so as to leave it mechanicaly undisturbed; otherwise the stratification of the samples might have become more or less blurred during the passage, when the cores were exposed to the perpetual rolling and pitching of the ship, and to the vibrations from the engines so difficult to avoid on board a ship, and to which the sediment is very sensitive. To keep the water content of the sediment unchanged it was necessary to flatten the cellophane sheets along the surface of the sample as carefully as possible, as water would distil into the space left free in the folds. When the material was very soft, as was often the case in the upper part of the cores, it was not possible to wrap up the samples in a satisfactory way, and then it could not be avoided that some damage was caused to the samples during the stay on board.

The choice of coring stations

Prior to the Swedish Deep-Sea Expedition 1947—48 the piston corer had never been tried in the open ocean. The experimental cruise of

the Skagerak in the Mediterranean Sea in 1946 (PETTERSSON 1946, KULLENBERG 1947) had turned out very favourably, but on the other hand conditions in the open ocean are considerably more difficult than in the Mediterranean. Therefore, it was considered necessary to choose such a route for the expedition that good weather conditions and moderate sea and swell could be expected. Accordingly the tropical belt was decided on as the principal working field, a decision well justified by events, as very few days were lost owing to rough weather. On the other hand, the experience gained during the circumnavigating cruise proved it possible to carry out a deep-sea coring with a long piston corer under much more difficult conditions than had been previously expected. However, this might to a certain degree be due to the fact that the »Albatross» was exceedingly well suited to the purpose. Thanks to carefully calculated measures by the former master of the ship, Captain EINAR SJÖSTRÖM, the properties of the »Albatross» as to stability were, in fact, extremely favourable.

During the first part of the expedition, i. e. the cruise from Gothenburg to Martinique, lack of time allowed but very few cores to be collected, and during the last part of the expedition, i. e. the cruise from Tangier to the West Indies and back to Gothenburg, the deep-sea coring had to stand back in favour of trawling. During the rest of the expedition it was planned normally to collect six cores a week. Every day we tried to find suitable topographic conditions as early in the morning as possible. The echo-sounder was served by a battery of storage cells and as no reserve battery was available, the echo-sounder could not be kept working continually, but had to be out of action several hours a day while the battery was recharged. This was done at the stations and during the night. The echo-sounder was started early in the mornings and the ship was stopped and a core was collected as soon as the bottom of the sea had been found to be smooth and horizontal for a couple of miles. To make tolerably sure that no topographic irregularities exist in the vicinity of a coring station, the ship should have been run back a few miles over the plain portion of the sea bottom before collecting the core, but this precaution was rarely taken, owing to lack of time. As a consequence, topographic irregularities sometimes appeared shortly after the ship had left the station. The demands on the smoothness of the bottom had to be modified according to the general topographic appearance of the various regions. In some regions the floor of the ocean was smooth and horizontal for hundreds of miles, and then not even minor irregularities were tolerated near a station. In other regions the landscape was very irregular, and then even a quite small area with a reasonably smooth bottom had to be accepted. In such cases the search for a suitable area was continued until late in the afternoon, and was discontinued only just in time to allow the coring operations to be brought to an end before darkness fell. In a few cases cores were collected at chosen positions, as at the centre of the Tyrrhenian Sea and in the Romanche Deep. A list of the coring stations is given below. The time directly devoted to core sampling during the cruise, i. e. the time spent on core sampling on the stations, amounted to 642 hours, or 27 days. The number of coring stations was 279, and 223 faultless cores were obtained with a total length of 1,792 m.

Accidents

Several attempts at obtaining sediment cores were unsuccessful during the Swedish Deep-Sea Expedition (*Vide* List of coring stations). We shall briefly review the main causes for this.

The corer may fall on the bottom. If this happens on a bottom which is not covered by sand, pebbles, rock, or a hard crust, sediment

Fig. 55. The piston rope has been broken and the corer lost. Photo Bruneau.

will stick to one side only of the tubing and the drive weights. It is therefore possible to obtain some information regarding the character of the bottom. If the presence of sediment on the tubing, and especially on the drive weights, prove that the tumble has not been caused by hard bottom, it was probably caused by some movement of the ship, which has to be handled in such a way as to eliminate the current. Then a new attempt may be more successful, which is not the case if the tumble was caused by hard bottom. In the last-mentioned instance the mouth-piece of the corer is sometimes scratched or knocked out of shape, which goes to prove that the bottom is covered by rock or boulders. If the bottom is covered by pebbles, this may be proved by the presence of a small sample retained by the core catcher. If the bottom is covered by sand the sample will generally be lost but the outside of the mouth-piece will be very bright after having been polished by the sand. However, as a rule the corer does not fall on a sandy bottom but is able to penetrate several metres into the sand, and collect a core. A crust may cause the sampler to fall, but sometimes the corer is able to run through the crust.

The coring tube may be broken. This is easily caused by a hard bottom if the corer is 15 m long, or more, and the sections of the tubing are joined by being screwed together, the end of one tube section being furnished with male screw-threads and the other one with female screw-threads. In such case the tubing will break in a joint. In order to avoid this the screw couplings (item 18) described on p. 48 were introduced during the cruise, whereupon no breaks occured. Instead the tube was bent at one or two occasions, once because the ship got a high velocity immediately before the corer reached the bottom.

The corer is not released. This is a very rare occurrence and appears always to be due to some mistake in the management of the corer.

The corer is released prematurely. This happened at several occasions when a coring was attempted after the cable had been used for trawling. It appears that the torsion of the cable is not the same one after a trawling as after the cable has been used to lower a heavy core sampler to the floor of the ocean. As a consequence the cable will make the corer rotate, and if the speed of rotation is sufficiently high, the corer is released prematurely. This does not apply to core samplers with a length of only 5 or 6 m, which could therefore be used successfully even after a trawling. After one coring with such a short sampler the cable has practically returned to its normal state of torsion, and a long sampler may be used without any risk of being prematurely released. It is also possible to check the rotation of the sampler by means of a vertical wing, which may damage a few metres of the cable, though. Another possibility to check the rotation of the sampler would be to apply a swivel between the cable and the sampler, which has never been attempted by me, however.

During the last Atlantic cruise of the »Albatross» the corer was released prematurely eight times before the cause was understood and a remedy found.

Removal of the top of the core by friction

In an ordinary gravity corer the friction between the sample and the inner walling of the coring tube will prevent the corer from obtaining long samples. Though this is not the case with a piston corer, the friction will, notwithstanding, cause a more or less considerable damage to the sample. In fact, when the core has been extracted from the lining, it is covered by a coat consisting of a stirred up sediment with a very loose consistency. The thickness of the coat may range between a fraction of a millimetre and several millimetres, and is generally decreasing downwards in the core. The coat is due to the friction between the sample and the tubing, making sediment to be carried away by the tubing from the cylindrical surface of the core as the core sampler is going down into the bottom. The same thing will happen when the sample is extracted from the lining tube by moving the tube with a stationary piston inserted into one end of it. Then a cushion consisting of a very loose matter accumulates before the piston, often as much as 50 cm^3, or the volume of 3 cm of the core. Each section of the lining has a length of 70 cm. The cushion is in some degree made up of the original coat previously referred to.

If the coat has a medium thickness of 0.5 mm, its volume amounts to about 70 cm^3 per meter of the core, which corresponds to 4 cm of the core per metre. If all this material is extracted from the top of the core, it will imply the destruction and removal of about $0.04 \cdot L$ cm from the top of the core, L cm denoting the length of the core. If, on the other hand, the material is carried away from all portions of the core in proportion to the tube length covered, i. e. the distance to the lower end of the corer the volume carried away from each metre of the core will be a linear function of the distance to the lower end of the core. A soft sediment can more easily be stirred and removed than a firm sediment, and as the upper part of the core has very often a looser consistency than the deeper parts, the upper part of the core is, therefore, more exposed to be removed in this manner than the deeper parts, even without considering the fact that the upper part of the core travels a longer way in the tubing than the deeper parts do. A comparatively undisturbed sample of the upper sediment layers can be obtained by collecting a short core separately, and this should always be done. Such a short core may be collected by means of an ordinary gravity corer, or by means of a short piston corer; a very handy piston corer designed for this purpose has been manufactured in the Oceanographic institute, Göteborg, though not until the Swedish Deep-Sea Expedition was finished.

The volume of the matter removed from the upper part of the core will obviously be the larger, the longer the core. Even though the removed matter will in the first hand be extracted from the periferal parts of the sample, leaving a central core more or less intact, the top of the core will not be able to survive, if the length of the core exceeds a certain value depending on the properties of the sediment and the roughness of the tubing. The length of the completely destroyed top portion of the core will be depending on the length of the core and the properties referred to. When cores as long as 15 or 20 m are collected, it is therefore advisable to collect a 10 m long core at the same position, as well as a short core by means of an ordinary gravity corer or a short piston corer.

The collection of short cores

It was planned to collect short and undisturbed cores of the upper sediment layers during the Swedish Deep-Sea Expedition, at each station where a long core was collected, by means of a short piston corer with a slightly modified construction. This apparatus did not

Fig. 56. A short sample has been collected. Photo Bruneau.

work in a satisfactory way at great depths, however, and it was necessary to use other corers.

Dr. Fred Phleger, who joined the expedition in Fort de France and left it in Colon, very kindly put three Hvorslev-Stetson corers with a length of 40 cm at our disposal. The corers were used as ordinary gravity corers without applying the free-fall principle. In order to save time one of them usually was attached to the big piston corer as a pilot weight together with the iron cylinders intended for the purpose. Sometimes the short corer was lowered separately by means of the serial winch.

Another short gravity corer was made on board the »Albatross» by Mr. Axel Jonasson. It was of the same type as the corer designed by Schoute for the Snellius expedition (Kuenen 1942). The principle was that the valve at the top of the tube was held wide open during the descent into the sediment so as to allow the water a free exit. Then the water in the tube could not acquire the velocity of the corer during the lowering, before the corer had reached the bottom, but would be more or less at rest as compared to the surrounding water masses and the sediment. Therefore the water in the tube would exercise a smaller pressure on the sediment than if the water exit port were narrow. Mr. Jonasson fitted the corer with a circular lid at the upper end which was left open during the lowering. The lid was set in such a way that it was kept open so long as the wire was tight. When the corer was stopped by the sediment the wire was slack, and a lead weight inserted between the wire and the rest of the corer descended a few millimetres and, in doing so, prepared the release of the lid by pushing back a small rod serving as a catch, preventing the lid from shutting the top end of the tube. When the hauling started, the catch was therefore left unsupported and a spring made the lid shut the tube with a considerable force. The lid was fitted with a packing which prevented water from entering the tube, thus making it easier for the sample to remain in the tube during the heaving. To the same end the mouth-piece was fitted with a core catcher similar to the one used in the piston corer. The corer was fitted with a plast lining.

Fig. 57. The »Albatross» at a coring station. Photo Bruneau.

LIST OF CORING STATIONS

Core No.	Station No.	Date	Hour	Position		Depth in m	Corer		Length of core cm	Rope paid out m	Remarks
				Lat.	Long.		Length m	Weight kg			
		1947									
21	1	13—7	0928—1750	N 45° 57′	W 07° 33′	4,780	15.5	1,120	—	4,780	Hard bottom; coring tube broken.
22	11	24—7	1530—2020	N 32° 02′	W 19° 30′	4,004	10.5	600	170	4,010	
23	12	26—7	0940—1620	N 31° 27′	W 23° 19′	5,403	10.5	760	—	5,415	The core catcher failed; sample lost.
24	15	27—7	1100—1730	N 30° 47′	W 25° 25′	5,464	10.5	880	1052	5,420	
25	16	30—7	0830—1500	N 26° 25′	W 34° 00′	5,450	15.5	1,070	1184	5,420	
26	17	31—7	0845—1430	N 25° 15′	W 36° 21′	5,640	15.5	1,110	1489	5,650	
27	19	1—8	1108—1615	N 23° 57′	W 38° 56′	4,975	15.5	1,110	1345	4,960	
28	20	2—8	1025—1540	N 22° 49′	W 41° 27′	5,945	15.6	1,290	1551	5,935	
29	22	4—8	1045—1315	N 21° 24′	W 46° 24′	≤ 3,180	5.5	390	208	3,180	
30	23	6—8	1340—1750	N 20° 01′	W 49° 18′	5,060	15.5	1,380	1133	5,060	
31	24	8—8	0705—1205	N 18° 23′	W 52° 57′	5,550	15.5	1,380	682	5,560	
32	28	12—8	1307—1503	N 14° 53′	W 61° 31′	2,665	5.5	500	400	2,660	
33	29	13—8	1112—1305	N 14° 54′	W 63° 55′	2,627	5.5	590	543	2,610	
34	30	14—8	0830—1430	N 14° 25′	W 65° 55′	4,900	15.5	1,160	1529	4,895	
35	42	29—8	1200—1615	N 06° 08′	W 80° 25′	3,000	10.5	800	1044	3,007	
36	45	30—8	0720—1017	N 05° 15′	W 81° 42′	3,850	15.5	1,200	1063	3,805	The corer was not released before it had penetrated 500 cm into the sediment.
37	47	1—9	0740—0850	N 03° 05′	W 84° 39′	2,750	15.6	1,400	—	2,740	Cable broken.
38	52	7—9	0630—0830	S 02° 52′	W 89° 50′	3,242	5.5	350	405	3,225	
39	55	8—9	1535—1722	S 02° 44′	W 92° 45′	3,617	5.5	350	528	3,600	
40	58	11—9	0947—1205	N 01° 04′	W 93° 20′	2,827	10.5	710	1017	3,820	
41	61	13—9	1155—1422	N 03° 20′	W 97° 53′	3,404	10.5	710	560	3,401	
42	63	15—9	0918—1205	N 05° 42′	W 101° 41′	3,190	10.5	830	778	3,205	
43	65	16—9	1418—1818	N 06° 21′	W 103° 42′	3,470	10.5	830	930	3,465	
44	66	17—9	0953—1244	N 06° 55′	W 104° 46′	3,565	10.5	830	967	3,497	
45	68	18—9	0850—1450	N 07° 40′	W 106° 21′	3,725	10.5	830	975	3,731	
46	69	19—9	0720—0915	N 08° 22′	W 108° 00′	3,800	10.5	830	979	3,775	
47	70	20—9	0707—0950	N 09° 14′	W 109° 39′	3,567	10.5	830	971	3,560	
48	73	22—9	0737—1020	N 11° 25′	W 113° 48′	4,090	10.5	830	695	4,085	
49	75	23—9	0725—0850	N 11° 39′	W 114° 15′	4,240	6	600	—	—	Cable broken.
51	78	26—9	1415—1715	N 15° 40′	W 123° 21′	4,300	10.5	800	969	4,320	
52	79	27—9	0735—1044	N 16° 35′	W 124° 48′	4,230	10.5	800	32	4,267	Manganese crust, the mouth-piece knocked out of shape.
53	81	29—9	0738—1041	N 15° 34′	W 127° 11′	4,730	10.5	800	348	4,750	
54	83	30—9	1108—1448	N 13° 17′	W 127° 25′	4,803	10.5	800	971	4,849	
55	85	1—10	0735—1041	N 11° 30′	W 127° 37′	4,916	10.5	800	(273)	4,930	Corer released prematurely.
56	86	2—10	0725—1119	N 09° 50′	W 128° 13′	4,629	10.5	800	(102)	4,644	Corer released prematurely.
57	87	3—10	0715—1110	N 08° 25′	W 128° 48′	4,607	10.5	800	485	4,627	
58	88	4—10	0715—1023	N 06° 44′	W 129° 28′	4,440	10.5	1,000	991	4,443	
59	90	6—10	1000—1456	N 03° 05′	W 133° 06′	4,338	10.5	1,000	972	4,356	
60	92	7—10	0948—1309	N 01° 35′	W 134° 57′	4,540	10.5	1,000	1013	4,573	
61	93	8—10	0757—1121	S 00° 06′	W 135° 58′	4,475	10.5	1,000	1029	4,452	
62	94	9—10	1130—1521	S 03° 00′	W 136° 26′	4,511	15	1,195	1479	4,510	
63	95	10—10	1100—1500	S 05° 37′	W 137° 53′	4,610	15	1,195	—	4,605	Hard bottom; coring tube broken.
64	97	20—10	1432—1750	S 12° 00′	W 144° 20′	5,008	5.5	370	90	5,035	The core catcher failed; part of sample lost.
65	98	21—10	1305—1706	S 13° 03′	W 146° 01′	5,055	5.5	370	—	5,047	Hard bottom; corer tumbled.
66	99	22—10	0730—1017	S 14° 12′	W 147° 37′	3,925	5.5	370	—	3,937	Hard bottom; corer tumbled.
67	100	23—10	0714—0959	S 15° 49′	W 148° 53′	4,290	5.5	370	20	4,323	Red clay and coral sand; corer tumbled.
68	102	5—11	0647—0948	S 13° 25′	W 149° 30′	4,630	5.5	370	—	4,625	Piston rope jammed, corer not released.
69	102	5—11	1452—1742	S 13° 25′	W 149° 30′	4,635	10.5	960	583	4,625	

Core No.	Station No.	Date	Hour	Position		Depth in m	Corer		Length of core cm	Rope paid out m	Remarks
				Lat.	Long.		Length m	Weight kg			
70	104	8—11	1324—1637	S 11° 15′	W 150° 30′	4,900	5.5	370	407	4,920	
71	105	10—11	0807—1107	S 07° 38′	W 152° 53′	5,015	10.5	960	1021	4,990	
72	105	10—11	1410—1723	S 13° 25′	W 152° 53′	5,015	15.5	1,120	1501	4,997	
73	106	12—11	0855—1208	S 04° 04′	W 152° 53′	5,200	15.5	1,120	1512	5,196	
74	109	14—11	0750—1035	S 00° 29′	W 151° 33′	4,575	15.5	1,120	1378	4,545	
75	112	15—11	1027—1305	N 00° 20′	W 150° 36′	4,400	10.5	880	909	4,405	
76	114	17—11	1312—1620	N 03° 45′	W 149° 44′	5,155	15.5	1,120	1373	5,153	
77	120	22—11	0857—1230	N 09° 30′	W 148° 40′	5,384	15.5	1,120	1401	5,358	
78	122	24—11	0840—1410	N 13° 24′	W 151° 12′	5,560	15.5	1,120	—	5,513	Coring tube broken.
79	124	15—12		N 18° 25′	W 160° 16′	5,293	5.5	360	—	—	Operations discontinued owing to heavy swell.
80	125	16—12	1329—1738	N 16° 19′	W 162° 57′	5,650	5.5	360	25	5,605	Corer tumbled; coarse sample.
81	127	17—12	1330—1636	N 14° 28′	W 164° 59′	5,460	5.5	520	20	5,455	Corer tumbled; manganese crust.
82	128	18—12	1336—1801	N 12° 16′	W 166° 48′	5,080	5.5	360	—	5,030	Corer not released; manganese crust.
83	130	20—12	0739—1045	N 08° 40′	W 169° 28′	5,456	11	810	296	5,440	
84	131	21—12	1449—1615	N 06° 21′	W 171° 52′	5,725	11	850	—	—	Operations discontinued owing to strong current.
85	132	22—12	1100—1424	N 05° 34′	W 172° 12′	5,590	11	890	1083	5,540	
86	134	23—12	0958—1358	N 04° 02′	W 172° 19′	5,560	11	810	1038	5,470	
87	136	24—12	0710—1040	N 02° 23′	W 173° 50′	5,560	11	810	1043	5,500	
88	138	26—12	1030—1401	S 02° 37′	W 177° 45′	5 770	11	810	(175)	5,690	Corer probably released prematurely.
89	139	27—12	1013—1315	S 02° 48′	W 178° 57′	5,465	11	930	1042	5,420	
90	140	30—12	1323—1736	S 03° 21′	E 174° 12′	4,830	6	670	563	4,743	
91	141	31—12	1311—1556	S 02° 50′	E 171° 18′	4,096	18	1,350	1606	4,015	
		1948									
92	142	2—1	0715—0928	S 01° 20′	E 167° 23′	3,942	6	700	557	3,875	
93	142	2—1	1106—1344	S 01° 20′	E 167° 23′	3,942	18	1,450	1535	3,880	
95	144	5—1	0927—1206	N 00° 34′	E 159° 59′	2,868	12	850	942	2,840	
96	145	6—1	0818—0955	N 00° 51′	E 157° 04′	2,194	12	850	978	2,160	
97	146	7—1	1054—1334	N 00° 48′	E 154° 46′	3,030	12	850	928	3,000	
98	148	9—1	1034—1317	N 01° 40′	E 152° 37′	3,670	12	940	1033	3,657	
99	149	11—1	1331—1748	N 02° 16′	E 148° 45′	6,080	12	940	151	6,027	
100	150	12—1	1331—1628	N 02° 09′	E 146° 52′	4,525	12	940	1080	4,500	
101	151	13—1	0727—1035	N 02° 11′	E 145° 47′	4,100	12	940	1097	4,080	
103	153	14—1	1322—1606	N 02° 25′	E 144° 04′	4,525	12	940	(168)	4,480	Corer released prematurely.
104	154	15—1	1331—1548	N 02° 36′	E 142° 32′	3,713	6	700	557	3,700	
105	155	17—1	0824—1106	N 02° 38′	E 139° 34′	4,275	12	940	1106	4,230	
106	156	19—1	0730—1004	N 02° 44′	E 134° 58′	4,240	12	850	1101	4,205	
107	158	21—1	0935—1231	N 04° 25′	E 130° 40′	(4,460)	12	850	835	4,445	
108	160	22—1	1238—1805	N 04° 43′	E 128° 06′	7,785	12	940	401	7,710	
109	162	23—1	0643—1600	N 05° 23′	E 127° 48′	8,390	12	940	—	8,340	Cable broken.
110	166	29—1	1357—1550	N 01° 01′	E 126° 56′	3,190	6	570	—	3,158	Corer not released.
111	167	29—1	1645—1808	N 01° 00′	E 126° 54′	2,685	6	570	(38)	2,675	Corer released prematurely.
112	168	30—1	0957—1147	S 01° 09′	E 126° 22′	2,417	6	700	564	2,410	
113	169	31—1	1020—1316	N 02° 44′	E 125° 22′	5,325	12	850	1114	5,263	
115	171	2—2	1552—1732	S 07° 00′	E 123° 04′	2,960	12	850	885	2,950	
116	172	3—2	1450—1721	S 07° 58′	E 121° 45′	4,375	12	850	(131)	4,410	Lining damaged by the piston.
118	175	5—2	1503—1759	S 07° 48′	E 119° 01′	4,585	12	850	—	4,535	Corer not released.
119	176	6—2	0907—1031	N 07° 51′	E 117° 32′	1,300	12	850	1197	1,285	
120	178	7—2	0702—0747	S 07° 46′	E 115° 11′	970	12	850	1175	950	
121	179	7—2	1354—1428	S 07° 33′	E 114° 25′	114	12	1,010	621	102	
122	181	15—2	1718—1750	S 07° 30′	E 113° 38′	68	12	1,010	980	56	
123	182	23—2	1017—1254	S 10° 15′	E 111° 53′	3,805	12	850	—	3,810	Coring tube broken, hard bottom.
124	183	24—2	1022—1520	S 10° 19′	E 109° 40′	6,410	12	900	20	6,375	Coarse sample.
125	185	25—2	0901—1329	S 10° 07′	E 108° 56′	6,875	12	910	771	6,850	

Core No.	Station No.	Date	Hour	Position		Depth in m	Corer		Length of core cm	Rope paid out m	Remarks
				Lat.	Long.		Length m	Weight kg			
126	186	26—2	1255—1631	S 10° 46′	E 106° 16′	5,735	12	980	35	5,697	Coarse sample.
127	188	27—2	1310—1640	S 11° 07′	E 103° 39′	5,735	12	980	1164	5,650	
128	189	28—2	0813—1124	S 11° 28′	E 102° 24′	5,225	12	980	1146	5,170	
130	194	1—3	0725—1049	S 11° 22′	E 99° 41′	5,440	12	980	700	5,400	Corer probably tumbled.
131	195	2—3	0707—0959	S 11° 10′	E 96° 42′	4,423	12	980	851	4,390	
132	198	3—3	0834—1220	S 11° 30′	E 94° 06′	5,280	12	980	—	5,235	Coring tube broken.
133	199	4—3	0935—1306	S 11° 33′	E 91° 26′	5,200	6.5	750	356	5,190	
134	205	8—3	1328—1642	S 04° 47′	E 88° 18′	5,050	7	500	(80)	5,055	Coring tube stopped by counter-weight rope.
135	206	9—3	1113—1405	S 02° 33′	E 88° 19′	4,840	7	980	—	4,830	Corer not released.
136	206	9—3	1540—1800	S 02° 33′	E 88° 19′	4,840	7	980	—	4,825	Corer not released, lost by accident.
137	208	11—3	1600—1837	N 01° 56′	E 88° 12′	4,300	12.7	980	659	4,280	
138	209	12—3	0811—1240	N 02° 45′	E 86° 53′	4,276	12.7	980	—	4,275	Coring tube broken.
139	210	13—3	0933—1203	N 03° 49′	E 84° 46′	4,186	6	750	(443)	4,170	Corer released too late.
140	212	15—3	0958—1228	N 05° 12′	E 80° 20′	4,249	6	750	455	4,245	
141	214	29—3	1427—1736	N 02° 18′	E 76° 02′	3,765	6.3	460	572	3,765	
142	215	30—3	1445—1714	N 00° 35′	E 75° 14′	4,048	6.3	460	601	4,052	
143	217	30—3	1130—1325	S 00° 31′	E 74° 33′	3,285	6.3	460	575	3,314	
144	219	1—4	1321—1624	S 01° 12′	E 72° 00′	4,417	12.2	900	761	4,410	
145	221	3—4	1041—1242	S 01° 20′	E 68° 20′	3,620	12.2	840	1023	3,615	
147	223	4—4	1017—1243	S 01° 19′	E 66° 16′	4,380	12.2	640	1115	4,387	
148	224	5—4	1403—1643	S 01° 20′	E 64° 00′	4,405	12.2	640	1152	4,380	
149	225	6—4	0740—1025	S 01° 22′	E 62° 38′	4,750	12.2	640	1179	4,730	
150	226	7—4	0800—1120	S 01° 37′	E 61° 00′	4,643	12.2	640	—	4,628	Hard bottom; corer tumbled.
151	227	8—4	1002—1240	S 02° 13′	E 58° 43′	4,370	6.3	770	—	4,386	Hard bottom; corer tumbled.
152	228	9—4	1115—1342	S 03° 18′	E 56° 47′	4,082	6.3	770	586	4,084	2 lining tubes deformed.
153	230	16—4	1412—1714	S 02° 18′	E 55° 33′	4,357	6.3	590	559	4,360	
154	231	17—4	1054—1414	S 00° 23′	E 54° 30′	4,855	12.1	940	1157	4,860	2 lining tubes deformed.
155	234	19—4	1050—1406	N 04° 28′	E 52° 48′	5,130	12.1	820	1157	5,117	
156	235	20—4	0932—1227	N 07° 14′	E 52° 49′	5,130	12.1	720	1111	5,107	
157	237	21—4	1345—1642	N 08° 05′	E 53° 03′	5,120	12.1	640	1006	5,098	
158	239	22—4	0856—1217	N 10° 06′	E 52° 45′	4,168	12.1	720	1079	4,167	
162	245	26—4	0945—1045	N 11° 57′	E 44° 18′	883	12.1	800	1119	883	
163	248	27—4	1634—1706	N 14° 12′	E 42° 18′	300	12.1	840	1136	285	
164	249	28—4	1535—1649	N 16° 05′	E 41° 27′	1,748	12.1	840	—	1,700	Core catcher failed; sample lost.
165	250	29—4	0843—0945	N 17° 24′	E 40° 17′	1,158	12.1	920	1124	1,146	
166	252	29—4	1559—1654	N 17° 56′	E 39° 57′	1,280	12.1	840	1115	1,283	
168	255	3—5	1621—1810	N 21° 20′	E 38° 10′	1,864	12.1	800	224	1,845	Corer stopped by crust.
169	256	4—5	1108—1148	N 23° 15′	E 37° 24′	860	6.3	580	98	864	Coarse sample.
176	261	15—5	0428—0500	N 31° 25′	E 32° 25′	30	6.3	200	(225)	23	Corer released too late.
178	263	15—5	0945—1024	N 31° 51′	E 32° 34′	381	6.3	380	537	378	
180	265	15—5	1510—1534	N 31° 59′	E 32° 06′	230	6.3	380	363	226	
184	272	16—5	1122—1213	N 32° 12′	E 30° 13′	1,176	6.3	500	582	1,167	
185	273	16—5	1711—1820	N 32° 47′	E 30° 33′	2,062	12.1	840	—	2,056	Short corer lost.
186	273	16—5	1825—1929	N 32° 47′	E 30° 33′	2,062	12.1	840	1109	2,056	
187	274	17—5	0531—0723	N 33° 59′	E 31° 02′	2,500	12.1	720	958	2,537	
188	275	17—5	1558—1736	N 33° 55′	E 30° 17′	2,810	12.1	800	886	2,890	
189	276	18—5	0714—0847	N 33° 54′	E 28° 29′	2,664	12.1	840	845	2,679	
190	278	19—5	0505—0639	N 33° 54′	E 26° 10′	2,900	12.1	920	947	2,920	
191	279	19—5	1053—1258	N 34° 24′	E 26° 11′	3,635	12.1	1,000	369	3,687	
192	280	19—5	1600—1728	N 34° 36′	E 25° 59′	2,680	12.1	1,000	863	2,664	
193	281	20—5	0633—0755	N 34° 12′	E 24° 22′	2,130	12.1	1,000	629	2,200	
194	283	20—5	1543—1722	N 34° 48′	E 23° 29′	3,000	12.1	1,000	728	3,005	
195	284	21—5	0840—1055	N 35° 51′	E 21° 53′	3,665	12.1	1,000	942	3,667	
196	285	21—5	1443—1716	N 35° 41′	E 21° 50′	4,270	12.1	1,000	658	4,298	
197	286	22—5	0921—1057	N 35 47′	E 20° 42′	2,940	12.1	1,000	752	2,950	
198	287	23—5	0841—1045	N 36° 13′	E 17° 28′	3,555	12.1	1,000	1166	3,566	

Core No.	Station No.	Date	Hour	Position		Depth in m	Corer		Length of core cm	Rope paid out m	Remarks
				Lat.	Long.		Length m	Weight kg			
199	288	24—5	0456—0640	N 37° 29′	E 15° 58′	2,370	12.1	800	847	2,369	
200	289	24—5	0949—1111	N 37° 33′	E 15° 24′	2,050	12.1	960	498	2,046	
201	290	25—5	1040—1223	N 39° 28′	E 13° 48′	3,070	12.1	840	1152	3,067	
205	295	26—5	1349—1621	N 40° 13′	E 12° 22′	3,610	20.8	1,190	1790	3,613	
206	296	28—5	1237—1415	N 43° 37′	E 07° 44′	1,890	12.1	720	—	1,957	Core catcher failed; sample lost.
207	297	3—6	1131—1326	N 43° 34′	E 07° 43′	2,230	12.1	920	810	2,250	
208	298	5—6	1545—1732	N 42° 38′	E 07° 09′	2,665	12.1	920	—	2,670	Coring tube broken; hard bottom.
209	301	7—6	1044—1212	N 38° 31′	E 03° 50′	2,595	10.5	780	1001	2,599	
210	303	8—6	0947—1120	N 37° 26′	E 01° 05′	2,795	10.5	700	934	2,782	
211	305	9—6	1355—1456	N 35° 55′	W 02° 20′	1,325	10.5	740	1024	1,323	
214	311	14—6	1111—1410	N 33° 29′	W 11° 03′	4,390	10.5	880	—	4,393	
215	312	16—6	1147—1412	N 29° 55′	W 17° 32′	4,320	10.5	880	832	4,348	
217	315	18—6	1045—1325	N 27° 27′	W 19° 43′	4,362	10.5	880	808	4,368	
218	316	19—6	1114—1429	N 25° 29′	W 21° 37′	4,675	10.5	960	—	4,660	Corer probably tumbled.
220	318	20—6	1525—1823	N 23° 13′	W 23° 01′	4,880	10.5	960	—	4,894	Corer released prematurely.
221	319	21—6	0812—1105	N 22° 31′	W 23° 28′	4,936	10.5	960	588	4,950	
223	320	23—6	0717—0935	N 20° 21′	W 20° 37′	3,820	10.5	960	822	3,835	
224	321	24—6	0730—0920	N 18° 50′	W 18° 24′	2,810	10.5	960	891	2,808	
225	322	24—6	1347—1520	N 18° 44′	W 18° 44′	2,973	10.5	880	973	2,984	
226	323	25—6	0748—0937	N 17° 57′	W 21° 03′	3,100	10.5	840	843	3,125	
227	324	26—6	0855—1043	N 16° 56′	W 23° 56′	3,450	10.5	840	909	3,475	
228	325	30—6	1240—1505	N 15° 53′	W 25° 27′	4,280	10.5	880	452	4,288	
229	326	1—7	1422—1658	N 13° 37′	W 25° 55′	4,810	10.5	960	1042	4,829	
230	328	3—7	0550—0856	N 10° 12′	W 26° 36′	5,500	15.6	1,080	1538	5,516	
232	330	5—7	1150—1607	N 07° 53′	W 24° 43′	4,975	15.6	1,080	(165)	4,975	Corer released prematurely.
233	331	6—7	1350—1620	N 07° 13′	W 22° 38′	4,125	15.6	1,080	1494	4,125	
234	332	7—7	1345—1605	N 05° 45′	W 21° 43′	3,579	15.6	1,080	1492	3,577	
235	334	9—7	0823—1105	N 03° 12′	W 20° 28′	4,560	15.6	1,080	1425	4,540	
236	335	10—7	0745—1050	N 02° 06′	W 20° 07′	5,065	15.6	1,080	1458	5,077	
238	339	13—7	1335—1830	N 00° 07′	W 18° 12′	7,316	15.6	1,080	1415	7,315	
239	340	14—7	1315—1810	N 00° 13′	W 18° 26′	7,599	15.6	1,080	175	7,535	Coarse sample.
241	343	17—7	1100—1335	N 01° 10′	W 19° 50′	4,345	15.6	1,080	1454	4,350	
242	345	19—7	1057—1255	N 00° 30′	W 25° 38′	3,620	10.6	880	1010	3,605	
243	347	20—7	1410—1630	N 00° 27′	W 27° 45′	3,740	10.6	800	1012	3,737	
246	350	22—7	0815—1015	N 00° 48′	W 31° 28′	3,209	10.6	800	879	3,217	
248	353	23—7	0830—1055	N 00° 16′	W 33° 40′	4,580	10.6	880	1026	4,580	
250	354	24—7	1330—1610	N 00° 06′	W 34° 41′	4,568	10.6	880	(247)	4,551	Corer released prematurely.
251	355	25—7	1330—1600	N 00° 37′	W 37° 07′	4,539	10.6	880	957	4,536	
252	356	26—7	1210—1500	N 02° 10′	W 39° 06′	4,483	15.8	1,070	1466	4,472	
254	358	28—7	0930—1200	N 04° 26′	W 41° 47′	4,353	15.8	1,070	(157)	4,337	Corer released prematurely.
255	359	29—7	0915—1155	N 06° 17′	W 43° 20′	4,534	15.8	1,070	1396	4,528	
257	360	30—7	1330—1620	N 07° 29′	W 45° 01′	4,470	15.8	1,070	888	4,460	
258	361	31—7	1010—1325	N 08° 15′	W 46° 30′	4,570	15.8	1,200	1073	4,554	
261	364	4—8	1240—1548	N 12° 54′	W 52° 55′	5,128	15.8	1,200	(50)	5,132	Corer released prematurely.
262	365	5—8	1250—1610	N 14° 32′	W 55° 05′	5,475	15.8	1,080	1267	5,481	
263	366	6—8	0920—1340	N 15° 44′	W 56° 50′	5,320	15.8	1,200	1483	5,320	
264	366	6—8	1450—1900	N 15° 44′	W 56° 50′	5,305	6	710	554	5,327	
265	367	7—8	1345—1700	N 16° 51′	W 58° 21′	5,832	15.8	1,200	—	—	Corer released prematurely.
266	368	9—8	0905—1220	N 19° 04′	W 63° 02′	5,953	15.8	1,200	(108)	—	Corer released prematurely.
267	369	10—8	0855—1035	N 17° 47′	W 65° 14′	2,105	15.8	1,200	1192	2,091	
271	374	25—8	1120—1525	N 28° 33′	W 59° 49′	6,310	6	750	—	6,293	Core catcher failed; sample lost.
272	375	26—8	1053—1405	N 29° 21′	W 58° 09′	5450—5920	6	670	(183)	5,602	
273	376	27—8	0934—1255	N 30° 29′	W 56° 07′	5,617	15.8	990	1558	5,625	
275	378	28—8	1440—1940	N 30° 46′	W 55° 56′	5,605	6	670	554	5,633	
276	379	30—8	0920—1225	N 33° 10′	W 50° 53′	4,852	15.8	1,070	1503	4,844	
278	380	31—8	1110—1425	N 33° 16′	W 49 00′	5,520	15.8	990	1517	5,505	
279	381	1—9	1255—1630	N 34° 06′	W 46° 12′	4,663	20.8	1,180	1917	4,654	
280	382	2—9	0755—1042	N 34° 57′	W 44° 16′	4,286	20.8	1,180	1868	4,288	

Core No.	Station No.	Date	Hour	Position		Depth in m	Corer		Length of core cm	Rope paid out m	Remarks
				Lat.	Long.		Length m	Weight kg			
281	383	2—9	1350—1630	N 34° 54′	W 44° 20′	4,292	20.8	1,220	(347)	4,281	Corer released prematurely.
283	385	4—9	1555—1835	N 37° 37′	W 41° 41′	4,940	6	670	552	4,961	
284	386	6—9	1055—1330	N 40° 32′	W 38° 17′	4,257	15.8	910	1436	4,304	
286	388	8—9	1020—1240	N 40° 40′	W 34° 58′	4,060	6	670	489	4,068	
288	390	9—9	1058—1235	N 41° 08′	W 31° 50′	2,684	15.8	1,070	1338	2,688	
289	391	9—9	1620—1800	N 41° 12′	W 31° 30′	2,640	15.8	1,070	1238	2,640	
290	392	10—9	0808—0930	N 41° 35′	W 29° 37′	1,995	15.8	1,190	660	1,990	Coring tube bent.
292	394	11—9	0725—0920	N 42° 16′	W 26° 36′	3,216	10.5	780	897	3,217	
293	395	11—9	1306—1500	N 42° 23′	W 26° 02′	3,485	10.5	940	903	3,473	
296	398	13—9	0832—1052	N 42° 27′	W 21° 08′	3,760	10.5	940	760	3,747	Core catcher lost; part of sample lost.
297	400	14—9	1038—1414	N 43° 04′	W 19° 40′	5,980	6	700	523	5,989	
299	402	18—9	1002—1229	N 47° 41′	W 12° 43′	4,288	6	830	538	4,304	

SHORT CORES COLLECTED WITH A CONVENTIONAL GRAVITY CORER

Core No.	Station No.	Date	Position		Depth in m
			Lat.	Long.	
		1947			
69	102	6—11	S 13° 25′	W 149° 30′	4,625
72	105	10—11	S 07° 38′	W 152° 53′	5,015
73	106	12—11	S 04° 04′	W 152° 53′	5,200
74	109	14—11	S 00° 29′	W 151° 33′	4,575
76	114	17—11	N 03° 45′	W 149° 44′	5,155
77	120	22—11	N 09° 30′	W 148° 40′	5,384
78	122	24—11	N 13° 24′	W 151° 12′	5,560
80	125	16—12	N 16° 19′	W 162° 57′	5,650
81	127	17—12	N 14° 28′	W 164° 59′	5,460
83	130	20—12	N 08° 40′	W 169° 28′	5,456
85	132	22—12	N 05° 34′	W 172° 12′	5,590
86	134	23—12	N 04° 02′	W 172° 19′	5,560
87	136	24—12	N 02° 23′	W 173° 50′	5,560
88	138	26—12	S 02° 37′	W 177° 45′	5,770
89	139	27—12	S 02° 48′	W 178° 57′	5,465
90	140	30—12	S 03° 21′	E 174° 12′	4,830
91	141	31—12	S 02° 50′	E 171° 18′	4,096
		1948			
92	142	2—1	S 01° 20′	E 167° 23′	3,942
93	142	2—1	S 01° 20′	E 167° 23′	3,942
95	144	5—1	N 00° 34′	E 159° 59′	2,868
96	145	6—1	N 00° 51′	E 157° 04′	2,194
97	146	7—1	N 00° 48′	E 154° 46′	3,030
98	148	9—1	N 01° 40′	E 152° 37′	3,670
99	149	11—1	N 02° 16′	E 148° 45′	6,080
100	150	12—1	N 02° 09′	E 146° 52′	4,525
101	151	13—1	N 02° 11′	E 145° 47′	4,100
103	153	14—1	N 02° 25′	E 144° 04′	4,525
104	154	15—1	N 02° 36′	E 142° 32′	3,713
105	155	17—1	N 02° 38′	E 139° 34′	4,275
106	156	19—1	N 02° 44′	E 134° 58′	4,240
107	158	21—1	N 04° 25′	E 130° 40′	4,445
108	160	22—1	N 04° 43′	E 128° 06′	7,785
121	179	7—2	S 07° 33′	E 114° 25′	114
122	181	15—2	S 07° 30′	E 113° 38′	68
123	182	23—2	S 10° 15′	E 11° 53′	3,805
126	186	26—2	S 10° 46′	E 106° 16′	5,735
127	188	27—2	S 11° 07′	E 103° 39′	5,735
128	189	28—2	S 11° 28′	E 102° 24′	5,225
130	194	1—3	S 11° 22′	E 99° 41′	5,440
131	195	2—3	S 11° 10′	E 96° 42′	4,423
132	198	3—3	S 11° 30′	E 94° 06′	5,280
133	199	4—3	S 11° 33′	E 91° 26′	5,200
135	206	9—3	S 02° 33′	E 88° 19′	4,840
146	222	3—4	S 01° 20′	E 68° 12′	3,290
147	223	4—4	S 01° 19′	E 66° 16′	4,380
148	224	5—4	S 01° 20′	E 64° 00′	4,405
149	225	6—4	S 01° 22′	E 62° 38′	4,750
152	228	9—4	S 03° 18′	E 56° 47′	4,082
153	230	16—4	S 02° 18′	E 55° 33′	4,360
154	231	17—4	S 00° 23′	E 54° 30′	4,855
155	234	19—4	N 04° 28′	E 52° 48′	5,130
156	235	20—4	N 07° 14′	E 52° 49′	5,130
157	237	21—4	N 08° 05′	E 53° 03′	5,120
160	241	24—4	N 12° 53′	E 49° 31′	2,221
161	242	24—4	N 12° 48′	E 49° 00′	1,760
162	245	26—4	N 11° 57′	E 44° 18′	883
163	248	27—4	N 14° 12′	E 42° 18′	300
164	249	28—4	N 16° 05′	E 41° 27′	1,748
165	250	29—4	N 17° 24′	E 40° 17′	1,158
166	252	29—4	N 17° 56′	E 39° 57′	1,280
167	253	3—5	N 21° 09′	E 38° 07′	2,346
169	256	4—5	N 23° 15′	E 37° 24′	860
170	257	5—5	N 24° 30′	E 36° 16′	1,130
171	258	5—5	N 24° 58′	E 35° 55′	751
172	259	6—5	N 26° 09′	E 35° 10′	1,038
173	260	6—5	N 26° 27′	E 34° 52′	940
174	261	15—5	N 31° 25′	E 32° 25′	30
175	261	15—5	N 31° 25′	E 32° 25′	29
176	261	15—5	N 31° 25′	E 32° 25′	29
177	262	15—5	N 31° 41′	E 32° 30′	32
178	263	15—5	N 31° 51′	E 32° 34′	381
179	264	15—5	N 31° 48′	E 32° 06′	80
180	265	15—5	N 31° 59′	E 32° 06′	230
181	266	16—5	N 31° 37′	E 30° 23′	23

Core No.	Station No.	Date	Position		Depth in m
			Lat.	Long.	
182	269	16—5	N 31° 49′	E 30° 20′	65
183	270	16—5	N 31° 53′	E 30° 19′	107
184	271	16—5	N 32° 12′	E 30° 13′	1,176
202	292	25—5	N 40° 30′	E 13° 43′	1 295
203	293	25—5	N 40° 18′	E 12° 54′	3,550
204	294	26—5	N 40° 12′	E 12° 21′	3,610
209	301	7—6	N 38° 31′	E 03° 50′	2,595
211	305	9—6	N 35° 55′	W 02° 20′	1,325
212	309	13—6	N 34° 56′	W 07° 54′	1,521
213	310	13—6	N 34° 50′	W 08° 01′	2,270
215	312	16—6	N 29° 55′	W 17° 32′	4,320
217	315	18—6	N 27° 27′	W 19° 43′	4,362
218	316	19—6	N 25° 29′	W 21° 37′	4,675
221	319	21—6	N 22° 31′	W 23° 28′	4,936
223	320	23—6	N 20° 21′	W 20° 37′	3,820
224	321	24—6	N 18° 50′	W 18° 24′	2,810
225	322	24—6	N 18° 44′	W 18° 44′	2,973
226	323	25—6	N 17° 57′	W 21° 03′	3,100
228	325	30—6	N 15° 53′	W 25° 27′	4,280
230	328	3—7	N 10° 12′	W 26° 36′	5,500
232	330	5—7	N 07° 53′	W 24° 43′	4,975
233	331	6—7	N 07° 13′	W 22° 38′	4,125
234	332	7—7	N 05° 45′	W 21° 43′	3,579
235	334	9—7	N 03° 12′	W 20° 28′	4,560
236	335	10—7	N 02° 06′	W 20° 07′	5,065
238	339	13—7	S 00° 07′	W 18° 12′	7,316
240	342	16—7	N 00° 59′	W 18° 37′	7,500
241	343	17—7	N 01° 10′	W 19° 50′	4,345
242	345	19—7	N 00° 30′	W 25° 38′	3,620
243	347	20—7	N 00° 27′	W 27° 45′	3.740
244	348	21—7	N 00° 59′	W 29° 22′	1,435
245	348	21—7	N 00° 58′	W 29° 23′	1,000
246	350	22—7	N 00° 48′	W 31° 28′	3,210
247	352	23—7	N 00° 15′	W 33° 37′	4,285
251	355	25—7	N 00° 37′	W 37° 07′	4,539

Core No.	Station No.	Date	Position		Depth in m
			Lat.	Long.	
252	356	26—7	N 02° 10′	W 39° 06′	4,483
255	359	29—7	N 06° 17′	W 23° 20′	4,534
257	360	30—7	N 07° 29′	W 45° 01′	4,470
258	361	31—7	N 08° 15′	W 46° 30′	4,570
259	362	2—8	N 11° 44′	W 51° 09′	5,020
260	363	3—8	N 12° 13′	W 51° 44′	5,035
261	364	4—8	N 12° 54′	W 52° 55′	5,128
262	365	5—8	N 14° 32′	W 55° 05′	5,475
263	366	6—8	N 15° 44′	W 56° 50′	5,320
264	366	6—8	N 15° 44′	W 56° 50′	5,320
265	367	7—8	N 16° 51′	W 58° 21′	5,832
266	368	9—8	N 19° 04′	W 63° 02′	5,953
267	369	10—8	N 17° 47′	W 65° 14′	2,105
269	371	20—8	N 24° 12′	W 63° 23′	5,855
270	373	23—8	N 28° 05′	W 60° 49′	5,760
271	374	25—8	N 28° 33′	W 59° 49′	6,310
272	375	26—8	N 29° 21′	W 58° 09′	5,600
273	376	27—8	N 30° 29′	W 56° 07′	5,617
276	379	30—8	N 33° 10′	W 50° 53′	4,852
278	380	31—8	N 33° 16′	W 49° 00′	5,520
280	382	2—9	N 34° 57′	W 44° 16′	4,286
281	383	2—9	N 34° 54′	W 44° 20′	4,292
283	385	4—9	N 37° 37′	W 41° 41′	4,940
284	386	6—9	N 40° 32′	W 38° 17′	4,257
285	387	7—9	N 40° 34′	W 35° 52′	4,570
286	388	8—9	N 40° 40′	W 34° 58′	4,060
287	389	9—9	N 41° 09′	W 32° 08′	2,871
280	390	9—9	N 41° 08′	W 31° 50′	2,684
289	391	9—9	N 41° 12′	W 31° 30′	2,640
290	392	10—9	N 41° 35′	W 29° 37′	1,995
291	393	10—9	N 41° 44′	W 28° 44′	2,501
292	394	11—9	N 42° 16′	W 26° 36′	3,216
294	396	12—9	N 41° 04′	W 24° 16′	3,749
295	397	12—9	N 41° 37′	W 23° 01′	4,155
297	400	14—9	N 43° 04′	W 19° 40′	5,980

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